State of the Great Lakes 2007 - Draft

DRAFT – JUNE 2007

Preface

The Governments of Canada and the United States are committed to providing public access to environmental information that is reported through the State of the Great Lakes reporting process. This commitment is integral to the mission to protect ecosystem health. To participate effectively in managing risks to ecosystem health, all Great Lakes stakeholders (e.g., federal, provincial, state and local governments; non-governmental organizations; industry; academia; private citizens, Tribes and First Nations) should have access to accurate information of appropriate quality and detail.

The information in this report, **State of the Great Lakes 2007**, has been assembled from various sources with the participation of many people throughout the Great Lakes basin. The data are based on indicator reports and presentations from the State of the Lakes Ecosystem Conference (SOLEC), held in Milwaukee, Wisconsin, November 1-3, 2006. The sources of information are acknowledged within each section.

Expanding upon previous State of the Great Lakes reporting systems, the 2007 information is presented in three different ways:

State of the Great Lakes 2007. This technical report contains the full indicator reports as prepared by the primary authors, the indicator category assessments, and management challenges. It also contains detailed references to data sources.

State of the Great Lakes 2007 Highlights. This report highlights key information presented in the main report.

State of the Great Lakes Technical Summaries Series. These summaries provide information from a variety of indicators such as: drinking water, swimming at the beaches, eating fish, air quality, aquatic invasive species, amphibians, birds, forests, coastal wetlands, the Great Lakes food web and special places such as islands, alvars and cobble beaches. In addition there is a technical summary for each of the lakes, plus the St. Clair-Detroit River ecosystem and the St. Lawrence River.

This approach of multiple reports addresses the needs of multiple audiences and also satisfies the U.S. *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies*, OMB, 2002, (67 FR 8452). The guidelines were developed in response to U.S. Public Law 106-554: H.R. 5658, Section 515(a) of the Treasury and General Government Appropriations Act for Fiscal Year 2001.

The State of the Lakes Ecosystem Conferences (SOLEC) and reports provide independent, science-based reporting on the state of the health of the Great Lakes basin ecosystem. Four objectives for the SOLEC process include:
To assess the state of the Great Lakes ecosystem based on accepted indicators
To strengthen decision-making and environmental management concerning the Great Lakes
To inform local decision makers of Great Lakes environmental issues
To provide a forum for communication and networking amongst all the Great Lakes stakeholders

The role of SOLEC is to provide clear, compiled information to the Great Lakes community to enable environmental managers to make better decisions. Although SOLEC is primarily a reporting venue rather than a management program, many SOLEC participants are involved in decision-making processes throughout the Great Lakes basin.

For more information about Great Lakes indicators and the State of the Lakes Ecosystem Conference, visit: www.binational.net or www.epa.gov/glnpo/solec or www.on.ec.gc.ca/solec.

1.0 Introduction

This **State of the Great Lakes 2007** report presents the compilation, scientific analysis and interpretation of data about the Great Lakes basin ecosystem. It represents the combined efforts of many scientists and managers in the Great Lakes community representing federal, Tribal/First Nations, state, provincial and municipal governments, non-government organizations, industry, academia and private citizens.

The seventh in a series of reports beginning in 1995, the **State of the Great Lakes 2007** provides an assessment of the Great Lakes basin ecosystem components using a suite of ecosystem health indicators. The Great Lakes indicator suite has been developed, and continues to be refined, by experts as part of the State of the Lakes Ecosystem Conference (SOLEC) process.

The SOLEC process was established by the governments of Canada and the U.S. in response to requirements of the Great Lakes Water Quality Agreement (GLWQA) for regular reporting on progress toward Agreement goals and objectives. Since the first conference in 1994, SOLEC has evolved into a two-year cycle of data collection, assessment and reporting on conditions and the major pressures in the Great Lakes basin. The year following each conference, a State of the Great Lakes report is prepared, based on information presented and discussed at the conference and post-conference comments. Additional information about SOLEC and the Great Lakes indicators is available at www.binational.net.

The **State of the Great Lakes 2007** provides assessments of 63 of approximately 80 ecosystem indicators and overall assessments of the categories into which the indicators are grouped: Contamination, Human Health, Biotic Communities, Invasive Species, Coastal Zones and Aquatic Habitats, Resource Utilization, Land Use-Land Cover, and Climate Change. Within most of the main categories are sub-categories to further delineate issues or geographic areas.

Authors of the indicator reports assessed the status of ecosystem components in relation to desired conditions or ecosystem objectives, if available. Five status categories were used (coded by color in this report):

Good. The state of the ecosystem component is presently meeting ecosystem objectives or otherwise is in acceptable condition.

Fair. The ecosystem component is currently exhibiting minimally acceptable conditions, but it is not meeting established ecosystem objectives, criteria, or other characteristics of fully acceptable conditions.

Poor. The ecosystem component is severely negatively impacted and it does not display even minimally acceptable conditions.

Mixed. The ecosystem component displays both good and degraded features.

Undetermined. Data are not available or are insufficient to assess the status of the ecosystem component.

Four categories were also used to denote current trends of the ecosystem component (coded by shape in this Highlights report):

Improving. Information provided shows the ecosystem component to be changing toward more acceptable conditions.

Unchanging. Information provided shows the ecosystem component to be neither getting better nor worse.

Deteriorating. Information provided shows the ecosystem component to be departing from acceptable conditions.

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Undetermined. Data are not available to assess the ecosystem component over time, so no trend can be identified.

For many indicators, ecosystem objectives, endpoints, or benchmarks have not been established. For these indicators, complete assessments are difficult to determine.

In 2006, the overall status of the Great Lakes ecosystem was assessed as mixed because some conditions or areas were good while others were poor. The trends of Great Lakes ecosystem conditions varied: some conditions were improving and some were worsening.

Some of the good features of the ecosystem leading to the *Mixed* conclusion include:

- Levels of most contaminants in herring gull eggs continue to decrease
- Phosphorus targets have been met in Lakes Ontario, Huron, Michigan and Superior.
- The Great Lakes are a good source for treated drinking water.
- Sustainable forestry programs throughout the Great Lakes basin are helping environmentally friendly management practices.
- Lake trout stocks in Lake Superior have remained self-sustaining, and some natural reproduction of lake trout is occurring in Lake Ontario and in Lake Huron.
- Mayfly (*Hexagenia*) populations have partially recovered in western Lake Erie.

Some of the negative features of the ecosystem leading to the *Mixed* conclusion include:

- Concentrations of the flame retardant PBDEs are increasing in herring gull eggs
- Nuisance growth of the green alga *Cladophora* has reappeared along the shoreline in many places
- Phosphorus levels are still above guidelines in Lake Erie.
- Non-native species (aquatic and terrestrial) are pervasive throughout the Great Lakes basin, and they continue to exert impacts on native species and communities.
- Populations of *Diporeia*, the dominant, native, bottom-dwelling invertebrate, continue to decline in Lake Michigan, Lake Huron, and Lake Ontario, and they may be extinct in Lake Erie.
- Groundwater withdrawals for municipal water supplies and irrigation, and the increased proportion of impervious surfaces in urban areas, have negatively impacted groundwater.
- Long range atmospheric transport is a continuing source of PCBs and other contaminants to the Great Lakes basin, and can be expected to be significant for decades.
- Land use changes in favour of urbanization along the shoreline continue to threaten natural habitats in the Great Lakes and St. Lawrence River ecosystems.
- Some species of amphibians and wetland-dependent birds are showing declines in population numbers – in part due to wetland habitat conditions.

The listing of the **State of the Great Lakes 2007** indicator reports, the categories, and the indicator assessments for 2007, 2005, 2003, and 2001 are provided in the following summary table. A complete listing of all indicators in the Great Lakes suite can be found in Section 6.0.

2.0 Assessing Data Quality

Through both the biennial Conferences and the *State of the Great Lakes* reports (Technical Report, Highlights, Summary Series), SOLEC organizers seek to disseminate the highest quality information available to a wide variety of environmental managers, policy officials, scientists and other interested public. The importance of this quality standard, including the availability of reliable and useful data, is implicit in the main objectives of the SOLEC process.

To ensure that data and information made available to the public by federal agencies adhere to a basic standard of objectivity, utility, and integrity, the U.S. Office of Management and Budget issued a set of Guidelines[1] in 2002. Subsequently, other U.S. federal agencies have issued their own guidelines for implementing the OMB policies. According to the Guidelines issued by the U.S. Environmental Protection Agency[2], information must be accurate, reliable, unbiased, useful and uncompromised though corruption or falsification. The U.S. EPA further amplified its Guidelines in 2003 with a review of "assessment factors" that the agency typically takes into account when evaluating the quality and relevance of scientific and technical information:[3]

- ***Soundness*** **-** *The extent to which the scientific and technical procedures, measures, methods or models employed to generate the information are reasonable for, and consistent with, the intended application*
- ***Applicability and Utility*** **-** *The extent to which the information is relevant for the Agency's intended use*

- ***Clarity and Completeness** - The degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations and analyses employed to generate the information are documented*
- ***Uncertainty and Variability** - The extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods or models are evaluated and characterized*
- ***Evaluation and Review** - The extent of independent verification, validation and peer review of the information or of the procedures, measures, methods or models.*

Recognizing the need to more formally integrate concerns about data quality into the SOLEC process, SOLEC organizers developed a Quality Assurance Project Plan (QAPP) in 2004. The QAPP recognizes that SOLEC, as an entity, does not directly measure any environmental or socioeconomic parameters. Existing data are contributed by cooperating federal, state and provincial environmental and natural resource agencies, non-governmental environmental agencies or other organizations engaged in Great Lakes monitoring. Additional data sources may include local governments, planning agencies, and the published scientific literature. Therefore, SOLEC relies on the quality of datasets reported by others. Characteristics of datasets that would be acceptable for indicator reporting include:

- *Data are documented, validated, or quality-assured by a recognized agency or organization.*
- *Data are traceable to original sources*
- *The source of the data is a known, reliable and respected generator of data.*
- *Geographic coverage and scale of data are appropriate to the Great Lakes Basin.*
- *Data obtained from sources within the United States are comparable with those from Canada.*
- *Gaps in data availability are identified if data sets are unavailable for certain geographic regions and/or contain a level of detail insufficient to be useful in the evaluation of a particular indicator.*
- *Data are evaluated for feasibility of being incorporated into indicator reports. Considerations include budgetary constraints in acquiring data, type and format of data, time required to convert data to usable form, and the collection frequency for particular types of data.*

SOLEC relies on a distributed system of information in which the data reside with the original providers. Although data reported through SOLEC are not centralized, clear links for accessibility of the data and/or the indicator authors are provided. The authors hold the primary responsibility for ensuring that the data used for indicator reporting meet criteria for objectivity, usefulness and integrity. Users of the indicator information, however, are obliged to evaluate the usefulness and appropriateness of the data for their own application, and they are encouraged to contact the authors with any concerns or questions.

The SOLEC indicator reporting process is intended to be open and collaborative. Indicator authors are generally subject matter experts who are the primary generators of data, who have direct access to the data, or who are able to obtain relevant data from one or more other sources and who can assess the quality of data for objectivity, usefulness and integrity. In some cases, authors may serve as facilitators or leaders to coordinate a workgroup of experts who collectively contribute their data and information, to arrange for data retrievals from agency or organization databases, or to review published scientific literature or conduct online data searches from trusted sources, e.g., U.S. census data or the National Land Cover Dataset.

Several opportunities are provided for knowledgeable people to review and comment on the quality of the data and information provided. These include:

- Coauthors - Most of the indicator reports are prepared by more than one author, and data are often obtained from more than one source. As the draft versions are prepared, the authors freely evaluate the data.
- Comments from the Author(s) - The section in each indicator report called "Comments from the Author(s)" provides an opportunity for the authors to describe any known limitations on the use or interpretation of the data that are being presented.
- Pre-SOLEC availability - The indicator reports are prepared before each Conference, and they are made available online to SOLEC participants in advance. Participants are encouraged to provide comments and suggestions for improvements, including any data quality issues.
- During SOLEC discussions - The Conferences have been designed to encourage exchange of ideas and interpretations among the participants. The indicator reports provide the framework for many of the discussions.
- Post-SOLEC review period - Following the Conferences, interested agencies, organizations and other stakeholders are encouraged to review and comment on the information and interpretations provided in the indicator reports.
- Preparation of *State of the Great Lakes* products - Prior to finalizing the Technical Report, Highlights, and Summary Series, any substantive comments on the indicator reports, including data quality issues, are referred back to the authors for resolution with the report editors.

The primary record and documentation of the indicator reports and assessments are the *State of the Great Lakes* reports. The *Technical Report* presents the full indicator reports as prepared by the primary authors. It also contains detailed references to the data sources. A *Highlights* report is also produced which refers to the detailed references and links. This approach of dual reports, one summary version and one with details and references to data sources, also satisfies *the Guidelines for Ensuring and Maximizing the Quality, Utility, and Integrity of Information Disseminated by Federal Agencies*, OMB, 2002, (67 FR 8452). The guidelines were developed in response to U.S. Public Law 106-554; H.R. 5658, Section 515 (a) of the Treasury and General Government Appropriations Act for Fiscal Year 2001.

[1]*Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies*, OMB, 2002, (67 FR 8452). The guidelines were developed in response to U.S. Public Law 106-554: H.R. 5658, Section 515(a) of the Treasury and General Government Appropriations Act for Fiscal Year 2001.

[2]*Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity, of Information Disseminated by the Environmental Protection Agency*. 2002. U.S. Environmental Protection Agency EPA/260R-02-008, 62pp.

[3]*Assessment Factors. A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information.* 2003. U.S. Environmental Protection Agency. EPA 100/B-03/001, 18pp.

3.0 What is being done to improve conditions?

In an effort to restore and preserve the Great Lakes, legislators, managers, scientists, educators and numerous others are responding to environmental challenges with multifaceted solutions. The responses and actions referenced here are intended to serve as examples of positive strides being taken in the Great Lakes basin to improve ecosystem conditions. Examples from both Canada and the United States and from each of the Great Lakes are included. There are many, many more actions that could have been recognized in this report. Each is an important part of our collective commitment to a clean and healthy Great Lakes ecosystem.

Strategic planning occurs at basin-wide, lake-wide and local scales. An example of strategic planning is the Canada-Ontario Agreement, a federal-provincial agreement that supports the restoration, protection, and conservation of the Great Lakes basin ecosystem. To achieve the collective goals and results, Canada and Ontario work closely with local and regional governments, industry, community and environmental groups. In the United States, more than 140 different federal programs help fund and implement environmental restoration and management activities in the basin. The Great Lakes Water Quality Agreement, Great Lakes Regional Collaboration and Federal Task Force, Great Lakes Binational Toxics Strategy, Lakewide Management Plans, Binational Partnerships, and Remedial Action Plans are other examples of strategic planning in the Great Lakes basin.

Research, monitoring and assessment efforts operating at various geographic scales are the backbone of management actions and decisions in the basin. Coordinated monitoring among Canadian and United States federal, provincial, state, and university groups began in 2003 to focus on monitoring physical, biological, and chemical parameters with monitoring occurring on a five-year rotation of one Great Lake per year. The International Joint Commission maintains a Great Lakes – St. Lawrence Research Inventory of the many funded projects that help increase our knowledge about the structure and function of the Great Lakes ecosystem.

Canada and the United States implement numerous **actions** across the basin at national, regional and local scales. For example, in Ontario, the City of Toronto is addressing water pollution through the Wet Weather Flow Management Master Plan, a long-term solution to reduce pollution from stormwater and combined sewer overflows.

Communities, states, the U.S. Environmental Protection Agency and local industry are working together to remediate contaminated sediments in U.S. Areas of Concern (AOCs) with funding provided through the U.S. Great Lakes Legacy Act. Since inception of the Act in 2002, sediment remediation has been completed at three U.S. AOC sites (Ruddiman Creek and Ruddiman Pond in Michigan, Black Lagoon in Michigan, and Newton Creek and Hog Island Inlet in Wisconsin).

The Oswego River AOC on Lake Ontario was delisted in 2006, the first removal of an AOC designation in the United States. In Canada, two AOCs have been delisted, both on Lake Huron (Collingwood Harbour in 1994 and Severn Sound in 2003). Delisting of an Area of Concern occurs when environmental monitoring has confirmed that the remedial actions taken have restored the beneficial uses in the area and that locally derived goals and criteria have been met.

Effective actions are often based on **collaborative work**. In 2005, the Nature Conservancy, the State of Michigan and The Forestland Group (a limited partnership), collaborated in a sale and purchase agreement that created the largest conservation project in Michigan's history. This purchase will protect more than 110,000 hectares (271,000 acres) through a working forest easement on 100,362 hectares (248,000 acres) and acquisition of 9,445 hectares (23,338 acres) in the Upper Peninsula of Michigan. By connecting approximately one million hectares (2.5 million acres), the project curbs land fragmentation and incompatible development by establishing buffers around conservation sites such as the Pictured Rocks National Lakeshore and Porcupine Mountains Wilderness State Park.

Lake Superior **communities** have embraced a goal of zero discharge of critical pollutants by engaging in a number of actions to remove contaminants. Efforts to reach this goal include electronic and hazardous waste collection events run by Earth Keepers, a faith-based environmental organization based in the Upper Peninsula of Michigan. On Earth Day 2006, over 272 metric tons (300 U.S. tons) of household hazardous waste, primarily household electronics, were collected, disposed of, or recycled. In Canada, more than 11,500 mercury switches from scrap automobiles were collected in 2005 through Ontario's mercury Switch Out program.

In many cases management and conservation actions are based on or supported by federal, state, provincial, or local **legislation**. For example, Ontario's Greenbelt Act of 2005 enabled the creation of a Greenbelt Plan to protect about 728,437 hectares (1.8 million acres) of environmentally-sensitive and agricultural land in the Golden Horseshoe region from urban development and sprawl. The Plan includes and builds upon approximately 324,000 hectares (800,000 acres) of land within the Niagara Escarpment Plan and the Oak Ridges Moraine Conservation Plan.

Proving that some **legislation** effectively crosses national borders, in December, 2005, the Great Lakes Governors and Premiers signed the *Annex 2001 Implementing Agreements* at the Council of Great Lakes Governors' Leadership Summit that will provide unprecedented protection for the Great Lakes–St. Lawrence River basin. The agreements detail how the states and provinces will manage and protect the basin and provide a framework for each state and province to enact laws for its protection, once the agreement is ratified.

Education and outreach about Great Lakes environmental issues are essential actions for fostering both a scientifically-literate public as well as informed decision-makers. The Lake Superior Invasive-Free Zone Project involves community groups in the inventorying and control of non-native invasive terrestrial and emergent aquatic plants through education. The project combines Canadian and United States programs at federal, state, provincial, municipal, and local levels and has the goal of eliminating non-native plants within a designated 291 hectare (720 acre) area.

A Shoreline Stewardship Manual developed for the Southeast shore of Lake Huron and promoted through workshops and outreach programs encourages sustainable practices to improve and maintain the quality of groundwater and surface water and the natural landscape features that support them. The Shoreline Stewardship Manual is a collaborative effort by the Huron County Planning Department, the University of Guelph, the Huron Stewardship Council, the Ausable Bayfield Conservation Authority, the Lake Huron Centre for Coastal Conservation, and the Friends of the Bayfield River, and a high level of community engagement has been instrumental in its success.

The Great Lakes Conservation Initiative of the Shedd Aquarium in Chicago aims to draw public attention to the value and vulnerabilities of the Great Lakes. With collaboration by Illinois-Indiana Sea Grant and the U.S. Fish and Wildlife Service, the Shedd Aquarium opened a new exhibit in 2006 which features many of the invasive species found in the Great Lakes. This exhibit provides public audiences with the opportunity to see many of these live animals and plants, and is also highlighted in teacher workshops.

As these examples show, there is much planning, information gathering, research and education occurring in the Great Lakes basin. Much more remains to be done to meet the goals of the GLWQA, but progress is being made with the involvement of all Great Lakes stakeholders.

4.0 Indicator Category Assessments and Management Challenges

Contamination

The transfer of natural and human-made substances from air, sediments, groundwater, wastewater, and runoff from non-point sources is constantly changing the chemical composition of the Great Lakes. Over the last 30 years, concentrations of some chemicals or chemical groups have declined significantly. There is a marked reduction in the levels of toxic chemicals in air, water, biota, and sediments. Many remaining problems are associated with local regions such as Areas of Concern. However, concentrations of several other chemicals that have been recently detected in Great Lakes have been identified as chemicals of emerging concern.

Levels of most contaminants in herring gull eggs continue to decrease in all the Great Lakes colonies monitored, although concentration levels vary from good in Lake Superior, to mixed in Lake Michigan, Lake Erie and Lake Huron, to poor in Lake Ontario. While the frequency of gross effects of contamination on wildlife has subsided, many subtle (mostly physiological and genetic) effects that were not measured in earlier years of sampling remain in herring gulls. Concentrations of flame-retardant polybrominated diphenyl ethers (PBDEs) are increasing in herring gull eggs.

Concentrations of most organic contaminants in the offshore waters of the Great Lakes are low and are declining, indicating progress in the reduction of persistent toxic chemicals. Indirect inputs of in-use organochlorine pesticides are most likely the current source of entry to the Great Lakes. Continuing sources of entry of many organic contaminants to the Great Lakes include indirect inputs such as atmospheric deposition, agricultural land runoff, and resuspension of contaminated sediments. Overall, mercury concentrations in offshore waters are well below water quality guidelines. Mercury concentrations in waters near major urban areas and harbors, however, exceed water quality criteria for protection of wildlife. Concentrations of polycyclic aromatic hydrocarbons (PAHs) and dioxins in offshore waters have declined below water quality guidelines, largely due to the control of point sources.

The status of atmospheric deposition of toxic chemicals is mixed and improving for polychlorinated biphenyls (PCBs), banned organochlorine pesticides, dioxins, and furans, but mixed and unchanging or slightly improving for PAHs and mercury across the Great Lakes. For Lake Superior, Lake Michigan, and Lake Huron, atmospheric inputs are the largest source of toxic chemicals due to the large surface areas of these lakes. While atmospheric concentrations of some substances are very low at rural sites, they may be much higher in some urban areas.

Juvenile spottail shiner, an important preyfish species in the Great Lakes, is a good indicator of nearshore contamination because the species limits its distribution to localized, nearshore areas during its first year of life. Total dichlorodiphenyltrichloroethane (DDT) in juvenile spottail shiner has declined over the last 30 years but still exceeds GLWQA criteria at most locations. Concentrations of PCBs in juvenile spottail shiner have decreased below the GLWQA guideline at many, but not all, sites in the Great Lakes.

The status of contaminants in lake trout, walleye and smelt as monitored annually in the open waters of each of the Great Lakes is mixed and improving for PCBs, DDT, toxaphene, dieldrin, mirex, chlordane, and mercury. Concentrations of PBDEs and other chemicals of emerging concern such as perflourinated chemicals, however, are increasing. Both the United States and Canada continue to monitor for these chemicals in whole fish tissues and have over 30 years of data to support the status and trends information.

Phosphorus concentrations in the Great Lakes were a major concern in the 1960s and 1970s, but private and government actions have reduced phosphorus loadings, thus maintaining or reducing phosphorus concentrations in open waters. However, high phosphorus concentrations are still measured in some embayments, harbors, and nearshore areas. Nuisance growth of the green alga *Cladophora* has reappeared along the shoreline in many places and may be related, in part, to increased availability of phosphorus.

Management Challenges:
Presently, there are no standardized analytical monitoring methods and tissue residue guidelines for new contaminants and chemicals of emerging concern, such as PBDEs.
PCBs from residual sources in the United States, Canada, and throughout the world enter the atmosphere and are transported long distances. Therefore, atmospheric deposition of PCBs to the Great Lakes will still be significant at least decades into the future.
Assessment of the capacity and operation of existing sewage treatment plants for phosphorus removal, in the context of increasing human populations being served, is warranted.
Monitoring of tributary, point source, and urban and rural non-point source contributions of phosphorus will allow tracking of various sources of phosphorus loadings.
Investigating the causes of *Cladophora* reappearances will aid in the reduction of its impacts on the ecosystem.

Chemical Integrity – What the Experts are Saying

Chemical Integrity of the Great Lakes – What the Experts are Saying
In addition to the ecosystem information derived from indicators, six presentations on the theme of "Chemical Integrity of the Great Lakes" were delivered at SOLEC 2006 by Great Lakes experts. The definition of Chemical Integrity proposed by SOLEC is "the capacity to support and maintain a balanced, integrated and adaptive biological system having the full range of elements and processes expected in a region's natural habitat." James R. Karr, 1991(modified)

The presentations focused on the status of anthropogenic (man-made) contaminants and imbalances in naturally-occurring chemicals in the Great Lakes basin. The key points of each presentation are summarized here.

Anthropogenic Chemicals
Ron Hites, Indiana University: While concentrations of banned or regulated toxic substances such as PCBs and PAHs have decreased over the past 30 years, the rate of decline has slowed considerably over the past decade. Virtual elimination of most of these chemicals will not occur for another 10 to 30 years despite restrictions or bans on their use. Further decreases in the environmental concentrations of PCBs, PAHs, and some pesticides may well depend on emission reductions in cities.

Derek Muir, Environment Canada: Some 70,000 commercial and industrial compounds are now in use, and an estimated 1,000 new chemicals are introduced each year. Several chemical categories have been identified as chemicals of emerging concern, including polybrominated diphenyl ethers (flame retardants), perfluorooctanyl sulfonate (PFOS) and carboxylates, chlorinated paraffins and naphthalenes, various pharmaceutical and personal care products, phenolics, and approximately 20 currently-used pesticides. PBDEs, siloxanes and musks are now widespread in the Great Lakes environment. Implementation of a more systematic program for monitoring new persistent toxic substances in the Great Lakes will require significant investments in instrumentation and researchers.

Joanne Parrot, Environment Canada: Some pharmaceuticals and personal care products appear to cause negative effects in aquatic organisms at very low concentrations in laboratory experiments. Some municipal waste water effluents within the Great Lakes discharge concentrations of these products within these ranges. There is some evidence that fish and turtles show developmental effects when exposed to municipal wastewater effluent in the laboratory. Whether these effects appear in aquatic organisms including invertebrates, fish, frogs, and turtles, in environments downstream of municipal wastewater effluent is not known, indicating the need for more research in this area.

Naturally-occurring Chemicals
Harvey Bootsma, University of Wisconsin-Milwaukee: Changes in levels of nitrate, chloride and phosphorus in Great Lakes waters are attributed to human activities, with potential effects on phytoplankton and bottom-dwelling algae. Changes in lake chemistry, shown through variations in calcium, alkalinity, and even chlorophyll, are linked to the biological activity of non-native

species. Non-native species also appear to be altering nutrient cycling pathways in the Great Lakes, by possibly intercepting nearshore nutrients before they can be exported offshore and transferring them to the lake bottom.

Susan Watson, Environment Canada: The causes and occurrences of taste and odor impairments in surface waters are widespread, erratic, and poorly characterized but are likely caused by volatile organic compounds produced by species of plankton, benthic organisms, and decomposing organic materials. In recent years, there has been an increase in the frequency and severity of nuisance algae such as *Cladophora* outbreaks in the Great Lakes, particularly in the lower Great Lakes. Type E botulism outbreaks and resulting waterbird deaths continue to occur in Lake Michigan, Lake Erie and Lake Ontario.

David Lam, Environment Canada: Models and supporting monitoring data are used to predict Great Lakes water quality. A post-audit of historical models for Great Lakes water quality revealed the general success of setting target phosphorus loads to reduce open water phosphorus concentrations.

Human Health

Levels of PCBs in sportfish continue to decline, progress is being made to reduce air pollution, beaches are better assessed and more frequently monitored for pathogens, and treated drinking water quality continues to be assessed as good. Although concentrations of many organochlorine chemicals in the Great Lakes have declined since the 1970s, sportfish consumption advisories persist for all of the Great Lakes.

The quality of municipally-treated drinking water is considered good. The risk of human exposure to chemicals and/or microbiological contaminants in treated drinking water is generally low. However, improving and protecting source water quality (before treatment) is important to ensure good drinking water quality.

In 2005, 74 percent of monitored Great Lakes beaches in the United States and Canada remained open more than 95 percent of the swimming season. Postings, advisories or closures were due to a variety of reasons, including the presence of *E. coli* bacteria, poor water quality, algae abundance, or preemptive beach postings based on storm events and predictive models. Wildlife waste on beaches can be more of a contributing factor towards bacterial contamination of water and beaches than previously thought.

Concentrations of organochlorine contaminants in Great Lakes sportfish are generally decreasing. However, in the United States, PCBs drive consumption advisories of Great Lakes sportfish. In Ontario, most of the consumption advisories for Great Lakes sportfish are driven by PCBs, mercury, and dioxins. Toxaphene also contributes to consumption advisories of sportfish from Lake Superior and Lake Huron. Monitoring for other contaminants, such as PBDEs, has begun in some locations.

Overall, there has been significant progress in reducing air pollution in the Great Lakes basin. However, regional pollutants, such as ground-level ozone and fine particulates, remain a concern, especially in the Detroit-Windsor-Ottawa corridor, the Lake Michigan basin, and the Buffalo-Niagara area. Air quality will be further impacted by population growth and climate change.

Management Challenges:
Maintenance of high-quality source water will reduce costs associated with treating water, promote a healthier ecosystem, and lessen potential contaminant exposure to humans.
Although the quality of treated drinking water remains good, care must be taken to maintain water treatment facilities.
One-fourth of monitored beaches still have beach postings or closures.
A decline in some contaminant concentrations has not eliminated the need for Great Lakes sportfish consumption advisories.
Most urban and local air pollutant concentrations are decreasing. However, population growth may impact future air pollution levels.

Biotic Communities

Despite improvements in levels of contaminants in the Great Lakes, many biological components of the ecosystem are severely stressed. Populations of the native species near the base of the food web such as Diporeia *and species of zooplankton are in decline in some of the Great Lakes. Native preyfish populations have declined in all lakes except Lake Superior. Significant natural reproduction of lake trout is occurring in Lake Huron and Lake Superior only. Walleye harvests have improved but are still below fishery target levels. Lake sturgeon are locally extinct in many tributaries and waters where they once spawned and flourished. Habitat loss and deterioration remain the predominant threat to Great Lakes amphibian and wetland-dependant bird populations.*

The aquatic food web is severely impaired in all the Great Lakes with the exception of Lake Superior. Zooplankton populations have declined dramatically in Lake Huron, and a similar decline is occurring in Lake Michigan. Populations of *Diporeia*, the dominant native benthic (bottom-dwelling) invertebrate in offshore waters, continue to decline in Lake Huron, Lake Michigan and Lake Ontario, and they may be locally extinct in Lake Erie. The decline of *Diporeia* coincides with the introduction of non-native zebra and quagga mussels. Both zooplankton and *Diporeia* are crucial food sources for many other species, so their population size and health impact the entire system.

The current mix of native and non-native (stocked and naturalized) prey and predator fish species in the system has confounded the natural balance within most of the Great Lakes. In all but Lake Superior, native preyfish populations have deteriorated. However, the recent decline of non-native preyfish (alewife and smelt) abundance in all Great Lakes except Lake Superior could have positive impacts on other preyfish populations. Preyfish populations are important for their role in supporting predator fish populations, so the potential effects of these changes will be a significant factor to be considered in fisheries management decisions.

Despite basin-wide efforts to restore lake trout populations that include stocking, harvest limits, and sea lamprey management, lake trout have not established self-sustaining populations in Lake Michigan, Lake Erie, and Lake Ontario. In Lake Huron, substantial and widespread natural reproduction of lake trout was observed starting in 2004 following the near collapse of alewife populations. This change may have been due to the reduced predation on juvenile lake trout by adult alewives and the alleviation of a trout vitamin deficiency problem caused by trout consuming alewives. In Lake Superior, lake trout stocks have recovered such that hatchery-reared trout are no longer stocked.

Reductions in phosphorus loadings during the 1970s substantially improved spawning and nursery habitat for many fish species in the Great Lakes. Walleye harvests have improved but are still below target levels. Lake sturgeon are now locally extinct in many tributaries and waters where they once spawned and flourished, although some remnant lake sturgeon populations exist throughout the Great Lakes. Spawning and rearing habitats have been destroyed, altered or access to them blocked. Habitat restoration is required to help re-establish vigorous lake sturgeon populations.

From 1995 to 2005, the American toad, bullfrog, chorus frog, green frog and northern leopard frog exhibited significantly declining population trends while the spring peeper was the only amphibian species that exhibited a significantly increasing population trend in Great Lakes coastal wetlands. For this same time period, 14 species of wetland-dependant birds exhibited significantly declining population trends, while only six species exhibited significantly increasing population trends.

The Great Lakes are now facing a challenge from viral hemorrhagic septicemia (VHS). This virus has affected at least 37 fish species and is blamed for fish kills in Lake Huron, Lake St. Clair, Lake Erie, Lake Ontario, and the St. Lawrence River.

Management Challenges:
Populations of *Diporeia* continue to decline in Lake Michigan, Lake Huron, and Lake Ontario, and may be locally extinct in Lake Erie. Management actions to address the declines may be ineffective until the underlying causes of the declines are identified.
The decline of *Diporeia* coincides with the spread of non-native zebra and quagga mussels. Cause and effect linkages between non-native species in the Great Lakes and ecological impacts are essential, however, they may be difficult to establish.
Identification of remnant lake sturgeon spawning populations should assist the selection of priority restoration activities to improve degraded lake sturgeon spawning and rearing habitats.
Protection of high-quality wetland habitats and adjacent upland areas will help support populations of wetland-dependent birds and amphibians.

Invasive Species

Activities associated with shipping are responsible for over one-third of the aquatic non-native species introductions to the Great Lakes. Total numbers of non-native species introduced and established in the Great Lakes have increased steadily since the 1830s. However, numbers of *ship-introduced aquatic species have increased exponentially during the same time period. High population density, high-volume transport of goods, and the degradation of native ecosystems have also made the Great Lakes region vulnerable to invasions from terrestrial non-native species. Introduction of these species is one of the greatest threats to the biodiversity and natural resources of this region, second only to habitat destruction.*

There are currently 183 known aquatic and 124 known terrestrial non-native species that have become established in the Great Lakes basin. Non-native species are pervasive throughout the Great Lakes basin, and they continue to exert impacts on native species and communities. Approximately 10 percent of aquatic non-native species are considered invasive and have an adverse effect, causing considerable ecological, social, and economic burdens.

Both aquatic and terrestrial wildlife habitats are adversely impacted by invasive species. The terrestrial non-native emerald ash borer, for example, is a tree-killing beetle that has killed more than 15 million trees in the state of Michigan alone as of 2005. The emerald ash borer probably arrived in the United States on solid wood packing material carried in cargo ships or airplanes originating from its native Asia.

Introductions of non-native invasive species as a result of world trade and travel have increased steadily since the 1830s and will continue to rise if prevention measures are not improved. The Great Lakes basin is particularly vulnerable to non-native invasive species because it is a major pathway of trade and is an area that is already disturbed.

Management Challenges:
A better understanding of the entry routes of non-native invasive species would aid in their control and prevention.
Prevention and control require coordinated regulation and enforcement efforts to effectively limit the introduction of non-native invasive species.
Prevention of unauthorized ballast water exchange by ships will eliminate one key pathway of non-native aquatic species introductions to the Great Lakes.
The unauthorized release, transfer, and escape of introduced aquatic non-native species and private sector activities related to aquaria, garden ponds, baitfish, and live food fish markets need to be considered.

Coastal Zones and Aquatic Habitats

Coastal habitats are degraded due to development, shoreline hardening and establishment of local populations of non-native invasive species. Wetlands continue to be lost and degraded. In addition to providing habitat and feeding areas for many species of birds, amphibians and fish, wetlands also serve as a refuge for native mussels and fish that are threatened by non-native invasive species.

The Great Lakes coastline is more than 17,000 kilometers (10,563 miles) long. Unique habitats include more than 30,000 islands, over 950 kilometers (590 miles) of cobble beaches, and over 30,000 hectares (74,131 acres) of sand dunes. Each coastal zone region is subject to a combination of human and natural stressors such as agriculture, residential development, point and non-point sources of pollution, and weather patterns. The coastal zone is heavily stressed, with many of the basin's 42 million people living along the shoreline.

Wetlands are essential for proper functioning of ecosystems and. provide a refuge for native fish from predation by the non-native ruffe and provide refuge for native mussels from non-native zebra mussels. The Great Lakes coastline includes more than 200,000 hectares (494,000 acres) of coastal wetlands, less than half of the amount of wetland area that existed prior to European settlement of the basin. An inventory of Great Lakes coastal wetlands in 2004 demonstrated that Lake Huron and Lake Michigan still have extensive wetlands, especially barrier-protected wetlands. Reductions in wetland area are occurring, however, due to filling, conversion to urban, residential, and agricultural uses, shoreline modification, water level regulation, non-native species invasions, and nutrient loading. Stressors, such as these, may also impact the condition of remaining wetlands and can threaten their natural function. Coastal wetland plant community health, which is indicative of overall coastal wetland health, varies across the Great Lakes basin. In general, there is deterioration of native plant diversity in many wetlands as shoreline alterations may cause habitat degradation and allow for easier invasion by non-native species.

Naturally fluctuating water levels are essential for maintaining the ecological health of Great Lakes shoreline ecosystems, especially coastal wetlands. Wetland plants and biota have adapted to seasonal and long-term water level fluctuations, allowing wetlands to be more extensive and more productive than they would be if water levels were stable. In 2000, Great Lakes water levels were lower than the 140-year average water level measured from 1860-2000. Furthermore, many climate change models predict lower water levels for the Great Lakes. Coastal wetlands that directly border the lakes and do not have barrier beaches may be able to migrate toward the lakes in response to lower water levels. Inland and enclosed wetlands would likely dry up and become arable or forested land.

Shoreline hardening, primarily associated with artificial structures that attempt to control erosion, can alter sediment transport in coastal regions. When the balance of accretion and erosion of sediment carried along the shoreline by wave action and lake currents is disrupted, the ecosystem functioning of coastal wetlands is impaired. The St. Clair, Detroit, and Niagara Rivers have a higher percentage of their shorelines hardened than anywhere else in the basin. Of the five Great Lakes, Lake Erie has the highest percentage of its shoreline artificially hardened, and Lake Huron and Lake Superior have the lowest percentages artificially hardened.

Groundwater is critical for maintaining Great Lakes aquatic habitats, plants and animals. Human activities such as groundwater withdrawals for municipal water supplies and irrigation, and the increased proportion of impervious surfaces in urban areas, have detrimentally impacted groundwater. On a larger scale, climate change could further contribute to reductions in groundwater storage.

Management Challenges:

Despite improvements in research and monitoring of coastal zones, the basin lacks a comprehensive plan for long-term monitoring of these areas. Long-term monitoring should be an important component of a comprehensive plan to maintain the condition and integrity of the coastal zones and aquatic habitats.

An educated public is essential to ensuring wise decisions about the stewardship of the Great Lakes basin ecosystem.
Protection of groundwater recharge areas, conservation of water resources, informed land use planning, raising of public awareness, and improved monitoring are essential actions for improving groundwater quality and quantity.

Resource Utilization

Although water withdrawals have decreased, overall energy consumption is increasing as population and urban sprawl increase throughout the Great Lakes basin. Human population growth will lead to an increase in the use of natural resources.

The population of the Great Lakes basin is approximately 42 million. Growth forecasts for the western end of Lake Ontario (known as the Golden Horseshoe) predict that this portion of the Canadian population will grow by an additional 3.7 million people by 2031. Population size, distribution, and density are contributing factors to resource use in the basin, although many trends have not been adequately assessed. In general, resource use is connected to economic prosperity and consumptive behaviors.

Although the Great Lakes and their tributaries contain 20 percent of the world's supply of surface freshwater, less than one percent of these waters is renewed annually through precipitation, run-off and infiltration. The net basin water supply is estimated to be 500 billion liters (132 billion gallons) per day. In 2000, water from the Great Lakes was used at a rate equal to approximately 35 percent of the available daily supply. The majority of water withdrawn is returned to the basin through discharge or run-off. However, approximately seven percent is lost through evapo-transpiration or depleted by human activities. Due to the shutdown of nuclear power facilities and improved water efficiency at thermal power plants, water use in Canada and the United States has decreased since 1980. In the future, increased pressures on water resources are expected to come from population growth in communities bordering the basin, and from climate change.

Population size, geography, climate, and trends in housing size and density all affect the amount of energy consumed in the basin. Electricity generation was the largest energy consuming sector in the Great Lakes basin.

Population growth and urban sprawl in the basin have led to an increase in the number of vehicles on roads, fuel consumption, and kilometers/miles traveled. Over a ten year period (1994-2004) fuel consumption increased by 17 percent in the U.S. states bordering the Great Lakes and by 24 percent in the province of Ontario. Kilometers/miles traveled within the same areas increased 20 percent for the United States and 56 percent for Canada. The increase in registered vehicles continues to outpace the increase in licensed drivers.

Management Challenges:
Increasing requests for water from communities bordering the basin, where existing water supplies are scarce or of poor quality will require careful evaluation.
Energy production and conservation need to be carefully managed to meet current and future energy consumption demands.

Population growth and urban sprawl are expected to challenge the current and future transportation systems and infrastructures in the Great Lakes basin.

Land Use-Land Cover

The Great Lakes basin encompasses an area of more than 765,000 square kilometers (295,000 square miles). How land is used impacts not only water quality of the Great Lakes, but also biological productivity, biodiversity, and the economy.

Data from 1992 and 2002 indicate that forested land covered 61 percent of the Great Lakes basin and 70 percent of the land immediately buffering surface waters, known as riparian zones. The greater the forest coverage in a riparian zone, the greater the capacity for the watershed to maintain biodiversity, store water, regulate water temperatures, and limit excessive nutrient and sediment loadings to the waterways. Urbanization, seasonal home construction, and increased recreational use are among the general demands being placed on forest resources nationwide. Additional disturbances caused by lumber removal and forest fires can also alter the structure of Great Lakes basin forests. However, the area of forested lands certified under sustainable forestry programs has significantly increased in recent years, exemplifying continued commitment from forest industry professionals to practices that help protect local ecosystem sustainability. Continued growth in these practices will lead to improved soil and water resources and increased timber productivity in areas of implementation.

Under the pressure of rapid population growth in the Great Lakes region, urban development has undergone unprecedented growth. Sprawl is increasing in rural and urban fringe areas of the Great Lakes basin, placing a strain on infrastructure and consuming habitat in areas that tend to have healthier environments than those that remain in urban areas. This trend is expected to continue, which will exacerbate other problems, such as longer commute times from residential to work areas, increased consumption of fossil fuels, and fragmentation of habitat. For example, at current development rates in Ontario, residential building projects are predicted to consume some 1,000 square kilometers (386 square miles) of the countryside, an area double the size of Toronto, by 2031. Also, vehicle gridlock could increase commuting times by 45 percent, and air quality could decline due to an estimated 40 percent increase in vehicle emissions.

In 2006, The Nature Conservancy Great Lakes Program and the Nature Conservancy of Canada Ontario Region released the *Binational Conservation Blueprint for the Great Lakes*. The Blueprint identified 501 areas across the Great Lakes that are a priority for biodiversity conservation. The Blueprint was developed by scientifically and systematically identifying native species, natural communities, and aquatic system characteristics of the region, and determining the sites that need to be preserved to ensure their long-term survival.

Management Challenges:
As the volume of data on land use and land conversion grows, stakeholder discussions will assist in identifying the associated pressures and management implications.
Comprehensive land use planning that incorporates "green" features, such as cluster development and greenway areas, will help to alleviate the pressure from development.

Managing forest lands in ways that protect the continuity of forest cover can allow for habitat protection and wildlife species mobility, therefore maintaining natural biodiversity.
Policies that favor an economically viable forestry industry will motivate private and commercial landowners to maintain land in forest cover versus conversion to alternative uses such as development.

Climate Change

A qualitative assessment of the indicator category Climate Change could not be supported for this report. Some observed effects in the Great Lakes region, however, have been attributed to changes in climate. Winters are getting shorter; annual average temperatures are growing warmer; extreme heat events are occurring more frequently; duration of lake ice cover is decreasing as air and water temperatures are increasing; and heavy precipitation events, both rain and snow, are becoming more common.

Continued declines in the duration and extent of ice cover on the Great Lakes and possible declines in lake levels due to evaporation during the winter are expected to occur in future years. If water levels decrease as predicted with increasing temperature, shipping revenue may decrease and the need for dredging could increase. Northward migration of species naturally found south of the Great Lakes region and invasions by warm water, non-native aquatic species will likely increase the stress on native species. A change in the distribution of forest types and an increase in forest pests are expected. An increase in the frequency of winter run-off and intense storms may deliver more non-point source pollutants to the lakes.

Management Challenges:
Increased modeling, monitoring and analysis of the effects of climate change on Great Lakes ecosystems would aid in related management decisions.
Increased public awareness of the causes of climate change may lead to more environmentally-friendly actions.

Salmon and Trout
Indicator #8

Overall Assessment

Status: **Mixed**

Trend: **Improving**

Primary Factors Determining Status and Trend: **The number of stocked salmonines per year is decreasing due to improvements in suppressing the abundance of the non-native preyfish, alewife. Many of the introduced salmonines are also reproducing successfully in the Great Lakes. The combined effect of a decrease in the number of alewife, as well as the increased health and reproduction of the salmonines is creating an improvement in the Great Lakes ecosystem.**

Lake-by-Lake Assessment

Lake Superior

Status: **Fair**

Trend: **Improving**

Primary Factors Determining Status and Trend: The number of stocked salmonines per year in Lake Superior is decreasing at a steady rate. Populations of salmon, rainbow trout and brown trout are being stocked at suitable rates to restore and manage indigenous fish species in Lake Superior.

Lake Michigan

Status: **Mixed**

Trend: **Slightly Improving**

Primary Factors Determining Status and Trend: The number of salmonines stocked each year in Lake Michigan is slightly declining. The goal for Lake Michigan is to establish self-sustaining lake trout populations. Currently, there are more salmon than lake trout stocked, which suggests that the lake trout are beginning to meet the self-sustaining goal for a balance in the ecosystem. This lake has the highest stocking rates out of all the Great Lakes.

Lake Huron

Status: **Fair**

Trend: **Improving**

Primary Factors Determining Status and Trend: The number of salmonines stocked each year in Lake Huron is declining. This lake has the second highest number of stocked salmonines, but the numbers are decreasing faster than Lake Superior, suggesting a larger reproduction rate and a balance in the ecosystem.

Lake Erie

Status: **Good**

Trend: **Improving**

Primary Factors Determining Status and Trend: Lake Erie is one of the lowest stocked out of all the Great Lakes. The objective for Lake Erie is to provide sustainable harvests of valued fish including lake trout, rainbow trout, and other salmonoids. Fisheries restoration programs in Ontario and New York State have established regulations to conserve the harvest and increase fish populations for the next five years.

Lake Ontario

Status:	**Mixed**
Trend:	**Unchanging**
Primary Factors Determining Status and Trend	Lake Ontario has the second largest stocking rates (after Lake Michigan). The number of stocked salmonines has slightly declined in the last couple decades, but stocking numbers have been fairly constant in the last four years. The main objective for Lake Ontario is to have a diversity of naturally produced salmon and trout, with an abundance of rainbow trout and the top predator to be Chinook salmon. There is an abundance of rainbow trout and Chinook salmon, but the salmon and trout are not being naturally produced based on the high numbers of stocked fish each year.

Purpose

•To assess trends in populations of introduced salmon and trout species;
•To infer trends in species diversity in the Great Lakes basin; and
•To evaluate the resulting impact of introduced salmonines on native fish populations and the preyfish populations that supports them.

Ecosystem Objective

In order to manage Great Lakes fisheries, a common fish community goal was developed by management agencies responsible for the Great Lakes fishery. The goal is:

"To secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic environment" (GLFC 1997).

Fish Community Objectives (FCOs) for each lake address introduced salmonines such as chinook and coho salmon, rainbow and brown trout (see Table 1 for definitions of fish terms). The following objectives are used to establish stocking and harvest targets consistent with FCOs for restoration of native salmonines such as lake trout, brook trout, and, in Lake Ontario, Atlantic salmon:

Lake Ontario (1999): Establish a diversity of salmon and trout with an abundant population of rainbow trout and the chinook salmon as the top predator supported by a diverse preyfish community with the alewife as an important species. Amounts of naturally produced (wild) salmon and trout, especially rainbow trout that are consistent with fishery and watershed plans.

Lake Erie and Lake St. Clair (2003): Manage the eastern basin to provide sustainable harvests of valued fish species, including…lake trout, rainbow trout, and other salmonids.

Lake Huron (1995): Establish a diverse salmonine community that can sustain an annual harvest of 2.4 million kg with lake trout the dominant species and stream-spawning species also having a prominent place.

Lake Michigan (1995): Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout, and establish self-sustaining lake trout populations.

Lake Superior (2003): Manage populations of Pacific salmon, rainbow trout, and brown trout that are predominantly self-sustaining but may be supplemented by stocking that is compatible with restoration and management goals established for indigenous fish species.

Term	**Definition**
Salmonine	Refers to salmon and trout species
Salmonid	Refers to any species of fish with an adipose fin, including trout, salmon, whitefish, graying, and cisco
Pelagic	Living in open water, especially where the water is more than 20 m deep

Table 1. Glossary of various terms used in this report

State of the Ecosystem

First introduced to the Great Lakes in the late 1870s, non-native salmonines have emerged as a prominent component of the Great Lakes ecosystem and an important tool for Great Lakes fisheries management. Fish managers stock non-native salmonines to suppress abundance of the non-native preyfish, alewife, thereby reducing alewife predation and competition with native fish, while seeking to avoid wild oscillations in salmomine-predator/alewife-prey ratios. In addition, non-native salmonines are stocked to create recreational fishing opportunities with substantial economic benefit (Rand and Stewart 1998).

After decimation of the native top predator (lake trout) by the non-native, predaceous sea lamprey, stocking of non-native salmonines increased dramatically in the 1960s and 1970s. Based on stocking data obtained from the Great Lakes Fishery Commission (GLFC), approximately 922 million non-native salmonines were stocked in the Great Lakes basin between 1966 and 2005. This estimate excludes the stocking of Atlantic salmon in Lake Ontario because they are native to this lake. Non-native salmonines also reproduce in the Great Lakes. For example, many of the chinook salmon in Lake Huron are wild and not stocked. This includes mostly Chinook salmon, followed by Rainbow trout. Since 2002, 74 million non-native salmonines have been stocked in the Great Lakes. Although, this is a large amount of fish being stocked, the number of stocked salmonines has actually decreased 32% from 2002 to 2004.

Of non-native salmonines, chinook salmon are the most heavily stocked, accounting for about 45% of all non-native salmonine releases (Figure 1). Rainbow trout are the second highest non-native stocked species, accounting for 25% of all non-native salmonine releases. Chinook salmon, which prey almost exclusively on alewife, are the least expensive of all non-native salmonines to rear, thus making them the backbone of stocking programs in alewife-infested lakes, such as Lakes Michigan, Huron and Ontario (Bowlby and Daniels 2002). Like other salmonines, chinook salmon are also stocked in order to provide an economically important sport fishery. While chinook salmon have the greatest prey demand of all non-native salmonines, an estimated 76,000 tonnes of alewife in Lake Michigan alone are consumed annually by all salmonine predators (Kocik and Jones 1999).

Data are available for the total number of non-native salmonines stocked in each of the Great Lakes from 1966-2005 (Figure 2).

Of the five major Great Lakes (excluding Lake St. Clair), Lake Michigan is the most heavily stocked, with a maximum stocking level in 1998 greater than 16 million non-native salmonines. In contrast, Lake Superior has the lowest rates of stocking, with a maximum greater than 5 million non-native salmonines in 1991. Lakes Huron and Erie both display a similar overall downward trend in stocking, especially in recent years. Lake Ontario has a constant, yet slightly declining trend in stocking. In Lake Ontario, this trend can be explained by stocking cuts implemented in 1993 by fisheries managers to lower prey consumption by salmonine species by 50% over two years (Schaner et al. 2001). Since the late 1980s, the number of non-native salmonines stocked in the Great Lakes has been nearly constant or slightly declining with the exception of a 1998 peak in Lakes Michigan and Huron.

Overall, the Great Lakes are improving based on a general trend of reduced numbers of stocked salmonines. The goal of creating a balanced ecosystem within each lake is occurring at different levels for each individual lake. Lakes Superior and Erie are improving at the fastest rates with the lowest stocking levels, while Lake Ontario is improving at the slowest rate out of all of the Great Lakes. Lake Michigan's stocking levels are declining slightly more than Lake Ontario's levels, but it also has the highest number of stocked salmon and trout. Lake Huron has higher stocking rates than Lake Erie and Superior, but the levels have been decreasing faster each year than any other lake.

The number of stocked salmonines per year in Lake Superior is decreasing at a steady rate. Populations of salmon, rainbow trout and brown trout are being stocked at suitable rates to restore and manage indigenous fish species in Lake Superior. Stocking rates have decreased in the last 5 years suggesting successful reproduction rates and suitable conditions for an improvement towards a balanced ecosystem in the near future.

The number of salmonines stocked each year in Lake Michigan is slightly declining. The goal for Lake Michigan is to establish self-sustaining lake trout populations. Currently, there are more salmon than lake trout stalked, which suggests that the lake trout are beginning to meet the self-sustaining goal for a balance in the ecosystem. This lake has the highest stocking rates out of all the Great Lakes.

The goal for Lake Huron is to make the lake trout the dominant species. The lake trout is one of the few native deepwater predators found in the Great Lakes. Their populations in Lake Huron and Lake Michigan were decimated in the 1950's by over-fishing and predation by the exotic sea lamprey (US Fish and Wildlife Service, 2005). The number of lake trout has increased in the last decade due to the decrease in the number of sea lampreys (Madenjian and Desorcie, 2004). This lake has the second highest number of stocked salmonines suggesting a low reproduction rate, but an improvement in the balance of the ecosystem since these stocking levels are decreasing.

Lake Erie is one of the lowest stocked out of all the Great Lakes. The objective for Lake Erie is to provide sustainable harvests of valued fish including lake trout, rainbow trout, and other salmonoids. Based on figure 1, the need for stalking has dropped dramatically over the last few years, suggesting that sustainable harvests are occurring in Lake Erie. Fisheries restoration programs in Ontario and New York State have established regulations to conserve the harvest and increase fish populations for the next five years (Lake Erie Lamp, 2003). This program is well on its way since there have already been improvements in the fish populations.

Lake Ontario has the second largest stocking rates, following Lake Michigan. The number of stocked salmonines has slightly declined in the last couple decades, but stocking numbers have been fairly constant in the last four years. The main objective for Lake Ontario is to have a diversity of naturally produced salmon and trout, with an abundance of rainbow trout and the top predator to be Chinook salmon. Rainbow trout are the second highest stocked fish in Lake Ontario, following Chinook salmon. Therefore, part of this goal has been met since the Chinook salmon are readily available as the top predator, and Rainbow trout are abundant in Lake Ontario because of the high stocking levels. However, the objective of having naturally producing salmon and trout has not been met due to the need for high stocking rates in Lake Ontario. The salmon and trout are not naturally producing based on the high numbers of stocking each year. Lake Ontario received a "mixed" rating rather than deteriorating rating because, although the objectives have not been met, there is still a need for high stalking levels. Salmon and trout are stalked not only to create a balance in the ecosystem, but for a popular recreational activity. Sport fishing has been a very popular activity in Lake Ontario for many years. Native lake trout are at the top of the food chain and would have disappeared if they weren't being stocked for sport fishing. Sport fishing is a $3.1 billion annual business, according to a recent industry study (Edgecomb, 2006). High stocking rates are needed to keep up with the popularity of sport fishing in Lake Ontario, which explains the increased need for higher stocking levels in Lake Ontario.

Pressures

The introduction of non-native salmonines into the Great Lakes basin, beginning in the late 1870s, has placed pressures on both the introduced species and the Great Lakes ecosystem. The effects of introduction on the non-native salmonine species include changes in rate of survival, growth and development, dispersion and migration, reproduction, and alteration of life-history characteristics (Crawford 2001).

The effects of non-native salmonine introductions on the Great Lakes ecosystem are numerous. Some of the effects on native species are; 1) the risk of introducing and transferring pathogens and parasites (e.g. furunculosis, whirling disease, bacterial kidney disease, and infectious pancreatic necrosis), 2) the possibility of local decimation or extinction of native preyfish populations through predation, 3) competition between introduced and native species for food, stream position, and spawning habitat, and 4) genetic alteration due to the creation of sterile hybrids (Crawford 2001). The introduction of non-native salmonines to the Great Lakes basin is a significant departure from lake trout's historic dominance as key predator.

With few exceptions (such as kokanee salmon), introduced salmonines are now reproducing successfully in portions of the basin, and they are considered naturalized components of the Great Lakes ecosystem. Therefore, the question is no longer whether non-native salmonines should be introduced, but rather how to determine the appropriate abundance of salmonine species in the lakes.

Within any natural system there are limits to the level of stocking that can be maintained. The limits to stocking are determined by the balance between lower and higher trophic level populations (Kocik and Jones 1999). Rand and Stewart (1998) suggest that predatory salmonines have the potential to create a situation where prey (alewife) is limiting and ultimately predator survival is reduced. For example, during the 1990s, chinook salmon in Lake Michigan suffered dramatic declines due to high mortality and high prevalence of Bacterial Kidney Disease (BKD) when alewife were no longer as abundant in the preyfish community (Hansen and Holey 2002). Salmonine predators could have been consuming as much as 53 percent of alewife biomass in Lake Michigan annually (Brown et al. 1999). While suppressing alewife populations, managers seek to avoid extreme “boom and bust” predator and prey populations, a condition not conducive to biological integrity. Currently managers seek to produce a predator/prey balance by adhering to stocking ceilings established for lakes such as Michigan and Ontario, based on assessment of forage species and naturally produced salmonines.

Because of their importance as a forage base for the salmonine sport fishery, alewife are no longer viewed as a nuisance by some managers (Kocik and Jones 1999). However, alewives prey on the young of a variety of native fishes, including yellow perch and lake trout, and they compete with native fishes for zooplankton. In addition, the enzyme thiaminase in alewives causes Early Mortality Syndrome (EMS) in salmonines that consume alewife, threatening lake trout rehabilitation in the lower four lakes and Atlantic salmon restoration in Lake Ontario. As alewife populations increase, massive over-winter die-offs can occur, particularly in severe winters, fouling local beaches that are used for recreation and impacting the health of the surrounding ecosystem.

Management Implications

In Lakes Michigan, Huron and Ontario, many salmonine species are stocked in order to maintain an adequate population to suppress non-native prey species (alewife) as well as to support recreational fisheries. Determining stocking levels that will avoid oscillations in the forage base of the ecosystem is an ongoing challenge. Alewife populations, in terms of an adequate forage base for introduced salmonines, are difficult to estimate as there is a delay before stocked salmon become significant consumers of alewife; meanwhile, alewife can suffer severe die offs in particularly severe winters.

Fisheries managers seek to improve their means of predicting appropriate stocking levels in the Great Lakes basin based on the alewife population. Long-term data sets and models track the population of salmonines and species with which they interact. However, more research is needed to determine the optimal number of non-native salmonines, to estimate abundance of naturally produced salmonines, to assess the abundance of forage species, and to better understand the role of non-native salmonines and non-native prey species in the Great Lakes ecosystem.
Chinook salmon will likely continue to be the most abundantly stocked salmonine species in Lakes Michigan, Huron, and Ontario because they are inexpensive to rear, feed heavily on alewife, and they are highly valued by recreational fishers. Fisheries managers should continue to model, assess, and practice adaptive management with the ultimate objective being to support fish

community goals and objectives that GLFC lake committees established for each of the Great Lakes.

Comments from the author(s)
This indicator should be reported frequently as salmonine stocking is a complex and dynamic management intervention in the Great Lakes ecosystem.

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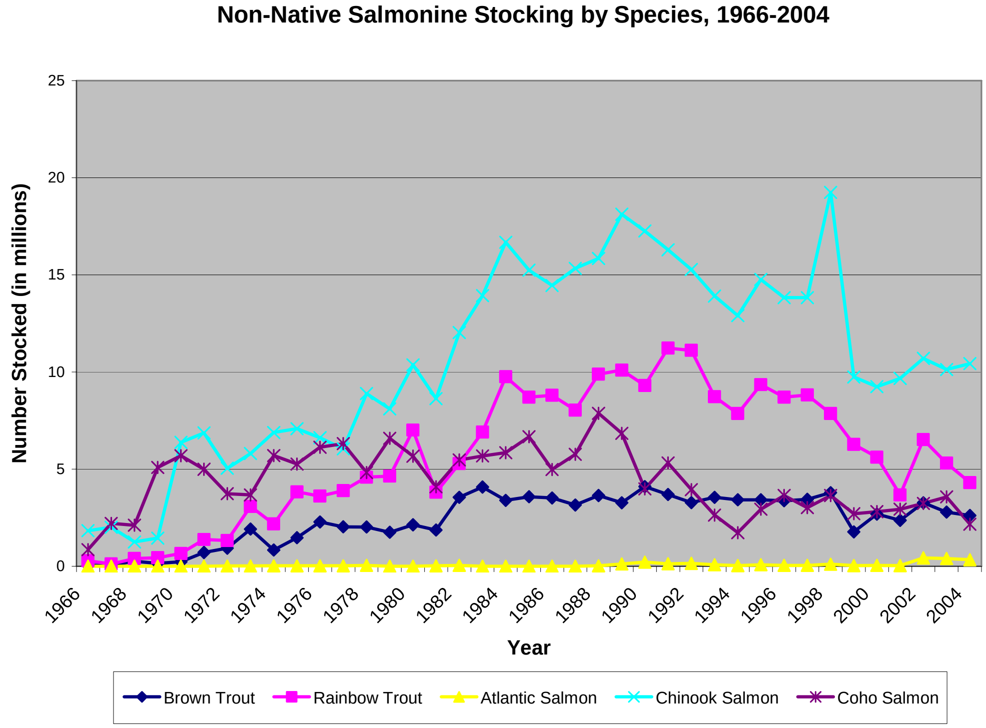

Figure 1. Non-Native salmonine stocking by species in the Great Lakes, 1966-2004 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking)

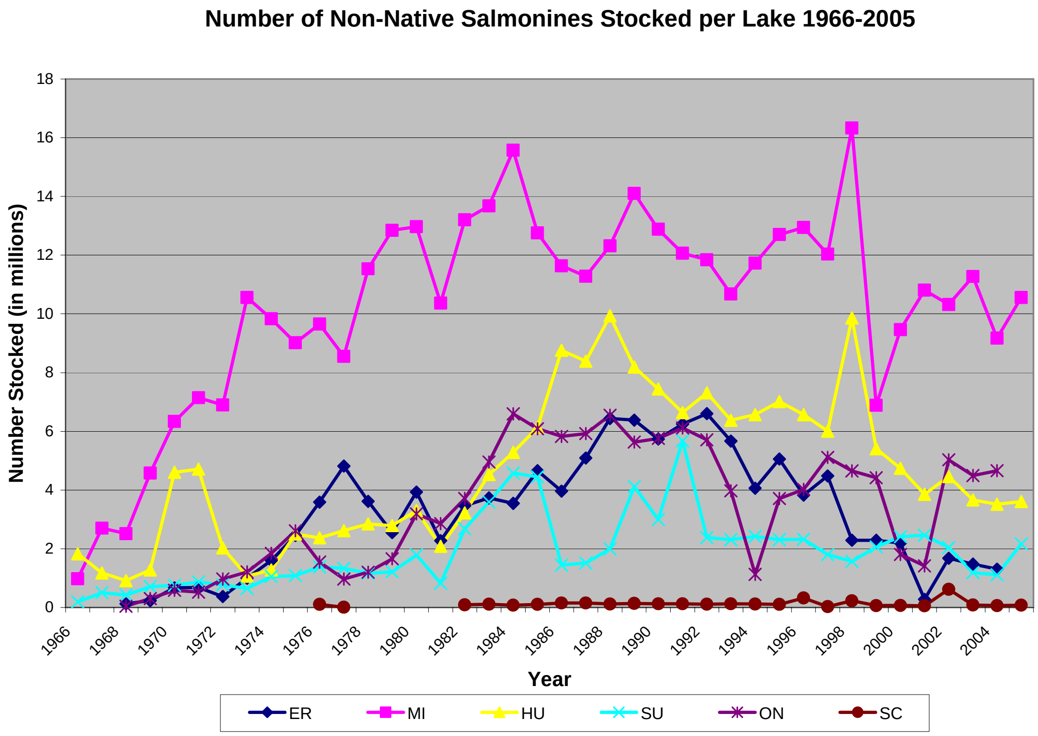

Figure 2. Total number of non-native salmonines stocked in the Great Lakes, 1966-2005 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking)

Walleye
Indicator #9

Overall Assessment

Status: **Fair**
Trend: **Unchanging**
Primary Factors Determining Status and Trend: **An exceptionally strong 2003 hatch has bolstered walleye abundance in nearly all of the Great Lakes and should keep them at low to moderate levels for the next several years. Low reproductive success post-2003 will not permit populations to increase in many areas. Fisheries harvests have improved in recent years but remain below targets in nearly all areas**.

Lake-by-Lake Assessment

Lake Superior

Status: Not Assessed Since Last Report
Trend: Undetermined
Primary Factors Determining Status and Trend: Recent harvest estimates were not available for this report. Through 2003, commercial yields were below the historical average while tribal harvest was above average.

Lake Michigan

Status: Fair
Trend: Undetermined
Primary Factors Determining Status and Trend: Recreational harvest was below historical levels in 2004-2005. Tribal fishery yields were not available but were well-above average in the four most recent years where data exist (2000-2003). Green Bay stocks appear to be stable, perhaps improving. Fishery yields remain well below targets of 100-200 metric tons per year.

Lake Huron

Status: Fair
Trend: Unchanging
Primary Factors Determining Status and Trend: Fishery yields are at historical average levels but far below targets of 700 metric tons each year. Commercial harvest trends continue to decline while recreational harvest trends are flat or perhaps improving. Reproductive success has greatly improved between 2003 and 2005 in Saginaw Bay and perhaps other parts of the lake, and is attributed to the decline of alewives.

Lake Erie

Status: Fair
Trend: Unchanging
Primary Factors Determining Status and Trend: The fisheries objective of sustainable harvests lake wide has not been realized since the late-1990s but has improved recently with contributions from the strong 2003 hatch. Commercial harvest increased substantially in 2005 while recreational fisheries remained static due to size restrictions. Harvest by both fisheries is expected to increase substantially in 2006.

Below-average reproductive success in 2004-2005 will reduce adult abundance over the next few years but the 2003 hatch should keep the population at low to moderate levels of abundance.

Lake Ontario

Status:	Fair
Trend:	Unchanging
Primary Factors Determining Status and Trend	After a decade long decline, walleye populations appear to have stabilized. Fishery yields are roughly half of the average over the past 30 years. Recent hatches should keep the population at current levels of abundance for the next several years.

Purpose

•To show status and trends in walleye populations in various Great Lakes habitats;
•To infer changes in walleye health; and
•To infer ecosystem health, particularly in moderately productive (mesotrophic) areas of the Great Lakes.

Ecosystem Objective

Protection, enhancement, and restoration of historically important, mesotrophic habitats that support natural stocks of walleye as the top fish predator are necessary for stable, balanced, and productive elements of the Great Lakes ecosystem.

State of the Ecosystem

Reductions in phosphorus loadings during the 1970s substantially improved spawning and nursery habitat for many fish species in the Great Lakes. Improved mesotrophic habitats (i.e., western Lake Erie, Bay of Quinte, Saginaw Bay and Green Bay) in the 1980s, along with interagency fishery management programs that increased adult survival, led to a dramatic recovery of walleyes in many areas of the Great Lakes, especially in Lake Erie. High water levels also may have played a role in the recovery in some lakes or bays. Trends in annual assessments of fishery harvests generally track walleye recovery in these areas, with peak harvests occurring in the mid-1980s to early 1990s followed by declines from the mid-1990s through 2000, and increases in most areas after 2000 (Figure 1). Total yields were highest in Lake Erie (annual average of about 4,500 metric tons, 1975-2005), intermediate in Lakes Huron (average of 90 metric tons) and Ontario (average of 224 metric tons), and lowest in Lakes Michigan (average of 14 metric tons) and Superior (average of 2 metric tons). Declines after the mid-1990s were possibly related to shifts in environmental states (i.e., from mesotrophic to less favorable oligotrophic conditions), variable reproductive success, influences from invading species, and changing fisheries. Recent improvements in abundance are due to a strong 2003 hatch across the Great Lakes Basin, presumably due to ideal weather conditions. Reproductive success has remained very strong since 2003 in Saginaw Bay, and perhaps other parts of Lake Huron, and is attributed to the decline of alewives in that lake during the same time period. In general, walleye yields peaked under ideal environmental conditions and declined under less favorable (i.e., non-mesotrophic) conditions. Overall, environmental conditions remain improved relative to the

1960s and early 1970s but concerns about food web disruption, pathogens (e.g., botulism, viruses), noxious algae, and watershed management practices persist.

Pressures

Natural, self-sustaining walleye populations require adequate spawning and nursery habitats. In the Great Lakes, these habitats exist in tributary streams and nearshore reefs, wetlands, and embayments, and they have been used by native walleye stocks for thousands of years. Degradation or loss of these habitats is the primary concern for the health of walleye populations and can result from both human causes, as well as from natural environmental variability. Increased human use of nearshore and watershed environments continues to alter the natural hydrologic regime, affecting water quality (i.e., sediment loads) and rate of flow. Environmental factors that affect precipitation patterns ultimately alter water levels, water temperature, water clarity and flow. Thus, global warming and its subsequent effects on temperature and precipitation in the Great Lakes basin may become increasingly important determinants of walleye health. Non-native invaders, like zebra and quagga mussels, ruffe, and round gobies continue to disrupt the efficiency of energy transfer through the food web, potentially affecting growth and survival of walleye and other fishes through a reduced supply of food. Recent experience in Lake Huron has elevated the concern over the predatory and competitive effects of the non-native alewife on walleye. In their absence, walleye reproductive success has surged, indicating that the deleterious effect of alewife predation on larval walleye may have been much greater than previously realized. Alterations in the food web can also affect environmental characteristics (like water clarity), which can in turn affect fish behavior and fishery yields. Pathogens, like viral hemorrhagic septicemia and botulism, may also be affecting walleye populations in some areas of the Great Lakes.

Management Implications

To improve the health of Great Lakes walleye populations, managers must enhance walleye reproduction, growth and survival rates. Most walleye populations are dependent on natural reproduction, which is largely driven by uncontrollable environmental events (i.e., spring weather patterns and alewife abundance). However, a lack of suitable spawning and nursery habitat is limiting walleye reproduction in some areas due to human activities and can be remedied through such actions as dam removal, substrate enhancement or improvements to watersheds to reduce siltation and restore natural flow conditions. Growth rates are dependent on weather (i.e., water temperatures), quality of the prey base, and walleye density, most of which are not directly manageable. Survival rates can be altered through fishery harvest strategies, which are generally conservative across all of the Great Lakes. Continued interactions between land managers and fisheries managers to protect and restore natural habitat conditions in mesotrophic areas of the Great Lakes are essential for the long term health of walleye populations. Elimination of additional introductions of invasive species and control of existing non-native species, where possible, is also critical to future health of walleyes and other native species.

Comments from the author(s)

Fishery yields are appropriate indicators of walleye health but only in a general sense. Yield assessments are lacking for some fisheries (recreational, commercial, or tribal) or in some years for all of the areas. Moreover, measurement units are not standardized among fishery types (i.e., commercial fisheries are measured in pounds while recreational fisheries are typically measured in numbers), which means additional conversions are necessary and may introduce errors. Also, “zero” values are not differentiated from “missing” data in the figure. Therefore, trends in yields across time (blocks of years) are probably better indicators than absolute values within any year, assuming that any introduced bias is relatively constant over time. Given the above, I recommend a 10-year reporting cycle on this indicator. Many agencies have developed, or are developing, population estimates for many Great Lakes fishes. Walleye population estimates for selected areas (i.e., Lake Erie, Saginaw Bay, Green Bay, and Bay of Quinte) would probably be a better assessment of walleye population health in the Great Lakes than harvest estimates across all lakes and I recommend switching to them as they become available in all areas.

Acknowledgments
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Data Sources
Fishery harvest data were obtained from the following sources:
Lake Superior: Ken Cullis, OMNR, ken.cullis@mnr.gov.on.ca
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Lake Ontario: Jim Hoyle, OMNR, jim.hoyle@mnr.gov.on.ca
Lake Ontario: Steve Lapan, NYSDEC, srlapan@gw.dec.state.ny.us

Various annual Lake Erie fisheries reports from the Ontario Ministry of Natural Resources, Ohio Department of Natural Resources, and the Great Lakes Fishery Commission commercial fishery data base were used as data sources.

Fishery data should not be used for purposes outside of this document without first contacting the agencies that collected them.

List of Figures
Figure 1. Recreational, commercial, and tribal harvest of walleye from the Great Lakes. Fish Community Goals and Objectives are: Lake Michigan, 100-200 metric tons; Lake Huron, 700 metric tons; Lake Erie, sustainable harvest in all basins.
Source: Chippewa Ottawa Resource Authority, Michigan Department of Natural Resources, New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Ohio Department of Natural Resources ,Wisconsin Department of Natural Resources

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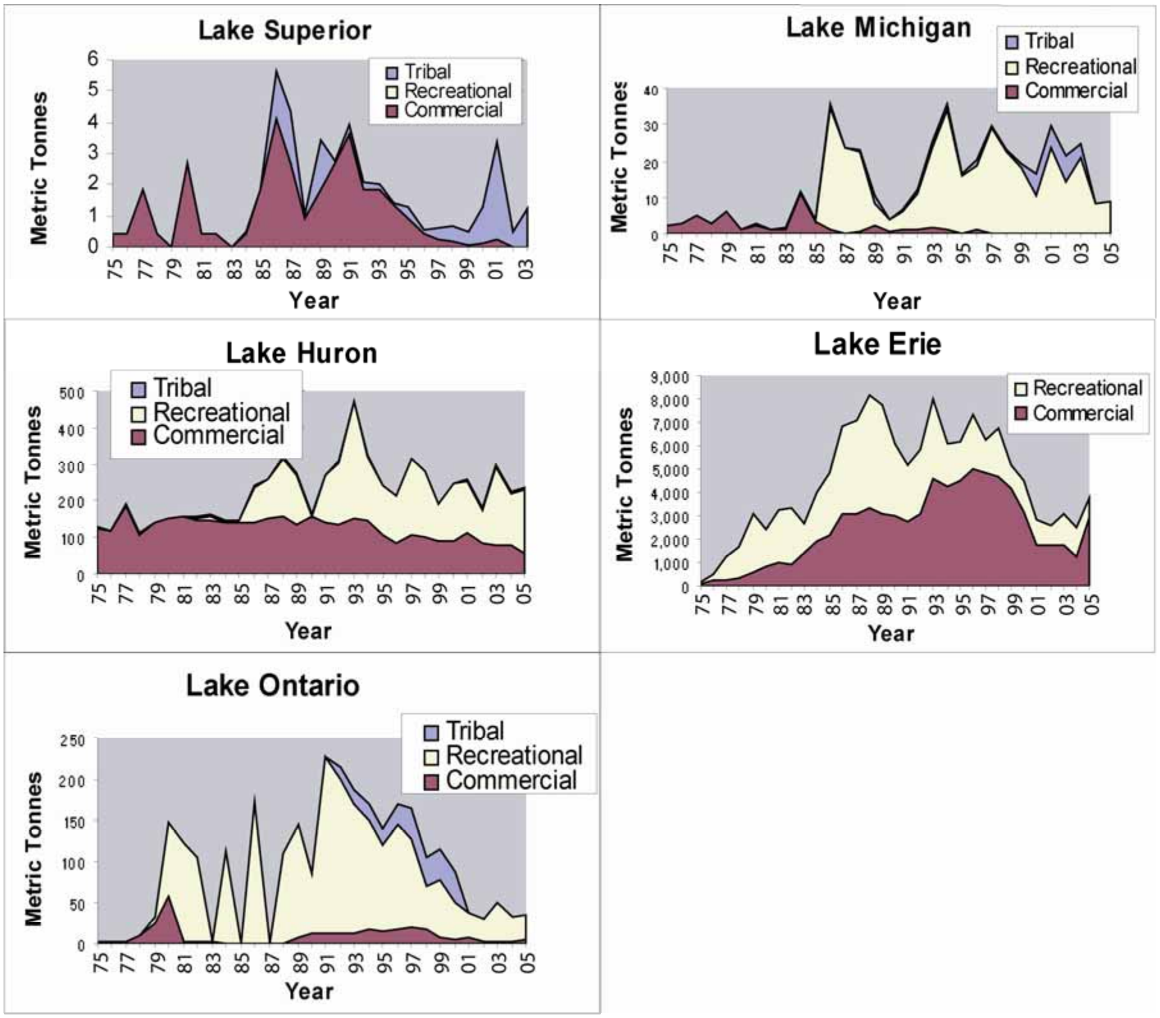

Figure 1. Recreational, commercial, and tribal harvest of walleye from the Great Lakes. Fish Community Goals and Objectives are: Lake Michigan, 100-200 metric tons; Lake Huron, 700 metric tons; Lake Erie, sustainable harvest in all basins.
Source: Chippewa Ottawa Resource Authority, Michigan Department of Natural Resources, New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Ohio Department of Natural Resources ,Wisconsin Department of Natural Resources

Preyfish Populations
Indicator #17

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**

Lake-by-Lake Assessment
Lake Superior

Status: Mixed
Trend: Improving

Lake Michigan

Status: Mixed
Trend: Deteriorating

Lake Huron

Status: Mixed
Trend: Deteriorating

Lake Erie

Status: Mixed
Trend: Deteriorating

Lake Ontario

Status: Mixed
Trend: Deteriorating

Purpose
• To assess the abundance and diversity of preyfish populations; and
• To infer the stability of predator species necessary to maintain the biological integrity of each lake.

Ecosystem Objective
The importance of preyfish populations to support healthy, productive populations of predator fishes is recognized in the Fish Community Goals and Objectives for each lake. For example, the fish community objectives for Lake Michigan specify that in order to restore an ecologically balanced fish community, a diversity of prey species at population levels matched to primary production and predator demands must be maintained. This indicator also relates to the 1997 Strategic Great Lakes Fisheries Management Plan Common Goal Statement for Great Lakes fisheries agencies.

State of the Ecosystem
Background
The preyfish assemblage forms important trophic links in the aquatic ecosystem and constitutes the majority of the fish production in the Great Lakes. Preyfish populations in each of the lakes are currently monitored on an annual basis in order to quantify the population dynamics of these

important fish stocks leading to a better understanding of the processes that shape the fish community and to identify those characteristics critical to each species. Populations of lake trout, Pacific salmon, and other salmonids have been established as part of intensive programs designed to rehabilitate (or develop new) game fish populations and commercial fisheries. These economically valuable predator species sustain increasingly demanding and highly valued fisheries, and information on their status is crucial. In turn, these apex predators are sustained by preyfish populations. In addition, some preyfishes, such as the bloater and the lake herring, which are native species, and the rainbow smelt, which is non native, are also directly important to the commercial fishing industry. Therefore, it is very important that the current status and estimated carrying capacity of the preyfish populations be fully understood in order to fully address (1) lake trout restoration goals, (2) stocking projections, (3) present levels of salmonid abundance and (4) commercial fishing interests.

The component of the Great Lakes' fish communities that we classify as preyfish comprises species – including both pelagic and benthic species – that prey on invertebrates for their entire life history. As adults, preyfish depend on diets of crustacean zooplankton and macroinvertebrates Diporeia and Mysis. This convention also supports the recognition of particle-size distribution theory and size-dependent ecological processes. Based on size-spectra theory, body size is an indicator of trophic level, and the smaller, short-lived fish that constitute the planktivorous fish assemblage discussed here are a discernable trophic group of the food web. At present, bloaters (*Coregonus hoyi*), lake herring (*Coregonus artedi*), rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), and deepwater sculpins (*Myoxocephalus thompsonii*), and to a lesser degree species like lake whitefish (*Coregonus clupeaformis*), ninespine stickleback (*Pungitius pungitius*), round goby (*Neogobius melanostomus*) and slimy sculpin (*Cottus cognatus*) constitute the bulk of the preyfish communities (Figure 1). The successful colonization of Lakes Michigan, Huron, Erie, and Ontario by non-native dreissenids, notably the zebra mussel (*Dreissena polymorpha*) in the early 1990s and more recently the quagga mussel (*Dreissena bugensis*), has had a significant impact on the trophic structure of those lakes by shunting pelagic planktonic production to mussels, an energetic dead end in the food chain as few native fishes can eat the mussels. As a result of profound ongoing changes in trophic structure in four Great Lakes, these ecosystems will continue to change, and likely in unpredictable ways. In Lake Erie, the preyfish community is unique among the Great Lakes in that it is characterized by relatively high species diversity. The preyfish community comprises primarily gizzard shad (*Dorosoma cepedianum*) and alewife (grouped as clupeids); emerald (*Notropis atherinoides*) and spottail shiners (*N. hudsonius*), silver chubs (*Hybopsis storeriana*), trout-perch (*Percopsis omiscomaycus*), round gobies, and rainbow smelt (grouped as soft-rayed); and age-0 yellow (*Perca flavescens*) and white perch (*Morone americana*), and white bass (*M. chrysops*) (grouped as spiny-rayed).

State of Preyfish Populations

Lake Ontario: Mixed, deteriorating

The non-native alewife, and to a lesser degree non-native rainbow smelt, dominate the preyfish community. Their populations remain at levels well below that of the early 1980s. Rainbow smelt have an abbreviated age and size structure that suggests the population is under heavy predation pressure. Abundance of the non-native round goby is increasing and round goby have the potential to negatively impact native, bottom-dwelling, preyfishes such as slimy and deepwater sculpins, and trout-perch. Deepwater sculpin, not reported from the lake since 1972, were collected sporadically in 1996-2004. During 2005-2006, catches of deepwater sculpin increased and juveniles dominated the catches suggesting that the long-depressed population was recovering. Deepwater ciscoes, however, have not been reported from the lake since 1983 and the large area of the lake they once occupied is largely devoid of fish for much of the year.

Lake Erie: Mixed, deteriorating
The preyfish community in all three basins of Lake Erie has shown declining trends. In the eastern basin, rainbow smelt (part of soft-rayed group) have shown declines in abundance over the past two decades. The declines have been attributed to lack of recruitment associated with expanding Driessenid colonization and reductions in productivity. The western and central basins also have shown declines in preyfish abundance associated with declines in abundance of age-0 white perch and rainbow smelt, although slight increases for white perch have been reported in the past couple years. The clupeid component of the preyfish community is at the lowest level observed since 1998 and well below the mean biomass during 1987-2005.. The biomass estimates for western Lake Erie were based on data from bottom trawl catches, depth strata extrapolations (0-6 m, and >6 m), and trawl net measurements using acoustic mensuration gear.

Lake Michigan: Mixed, deteriorating
Bloater abundance in Lake Michigan fluctuated greatly during 1973-2005, as the population showed a strong recovery during the 1980s but rapidly declined during the late 1990s. Bloaters may be cycling in abundance with a period of about 30 years. The substantial decline in alewife abundance during the 1970s and early 1980s has been attributed to increased predation by salmon and trout. The deepwater sculpin population exhibited a strong recovery during the 1970s and early 1980s, and this recovery has been attributed to the decline in alewife abundance. Alewives have been suspected of interfering with reproduction by deepwater sculpins by feeding upon deepwater sculpin fry. Slimy sculpin abundance appeared to be primarily regulated by predation by juvenile lake trout. Slimy sculpin is a favored prey of juvenile lake trout. Temporal trends in abundance of rainbow smelt were difficult to interpret. Yellow perch year-class strength in 2005 was the highest on record dating back to 1973. Thus, early signs of a recovery by the yellow perch population in the main basin of Lake Michigan were evident. The first catch of round gobies in our annual lakewide survey occurred in 2003, and round goby abundance in the main basin of the lake has remained low through 2005.

Lake Huron: Mixed, deteriorating
The Lake Huron fish community changed dramatically during 2003-2006, primarily due a 99% decline in alewife numbers. Loss of alewife appears due to heavy salmonid predation that resulted from increased Chinook salmon abundance as a result of wild reproduction. Alewife decline was followed immediately by increased reproduction of other fish species; record year classes of walleye and yellow perch were produced in Saginaw Bay, while in the main basin increased reproduction by bloaters (chubs), rainbow smelt, and deepwater sculpins was observed. In 2004, USGS surveys captured 22 wild juvenile lake trout -- more than had been captured in the 30 year history of those surveys. However, despite increased reproduction by prey species, biomass remains low because newly recruited fish are still small. No species has taken the place of alewife, and prey biomass has declined by over 65%. Salmon catch rates by anglers declined, as did average size and condition of those fish. The situation is exacerbated by changes at lower trophic levels. The deepwater amphipod Diporeia has declined throughout Lake Huron's main basin, and the zooplankton community has grown so sparse that it resembles the assemblage

found in Lake Superior. The reasons underlying these changes are not known, but the most widely held hypothesis is that zebra and quagga mussels are shunting energy into pathways that are no longer available to fish.

Lake Superior: Mixed, improving
Since 1994, biomass of the Lake Superior preyfish has declined compared to the peak years in 1986, 1990, and 1994, a period when lake herring was the dominant preyfish species and wild lake trout populations were starting to recover. Since the early 1980s, dynamics in preyfish biomass have been driven largely by variation in recruitment of age-1 lake herring. Strong year classes in 1984, 1988-1990, 1998, and most recently 2003 were largely responsible for peaks in lake herring biomass in 1986, 1990-1994, 1999, 2004-2005. Prior to 1984, the nonnative rainbow smelt was the dominant preyfish, but fluctuating population levels and recovery of native coregonids after 1984 resulted in reduced biomass and rank among preyfish species. During 2002-2004, rainbow smelt biomass declined to the lowest levels in the time series, though a moderate recovery occurred in 2005. There is strong evidence that declines in rainbow smelt biomass are tied to increased predation by recovered lake trout populations. Biomass of bloater and lake whitefish has increased since the early 1980s, and biomass for both species has been less variable than that of lake herring. Other preyfish species, notably sculpins, burbot, and ninespine stickleback have declined in abundance since the recovery of wild lake trout populations in the mid-1980s. Thus, the current state of the Lake Superior preyfish community appears to be largely the result of increased predation by recovered wild lake trout stocks and, to a lesser degree, the resumption of human harvest of lake trout, lake herring, and lake whitefish.

Pressures
The influences of predation by salmon and lake trout on preyfish populations appear to be common across all lakes. Additional pressures from *Dreissena*, which is linked to the collapse of Diporeia are strong in all lakes save Superior. Bottom-up effects on the preyfishes have already been observed in Lakes Ontario, Huron, and Michigan suggesting that dynamics of preyfish populations in those lakes could be driven by bottom-up rather than top-down effects in future years, Moreover, the effect of non-native zooplankters, *Bythotrephes* and *Cercopagis*, on preyfish populations, although not fully understood at present, has the potential to increase bottom up pressure.

Management Implications
Recognition of significant predation effects on preyfish populations has resulted in recent salmon stocking cutbacks in Lakes Michigan and Huron and only minor increases in Lake Ontario. However, even with a reduced population, alewives have exhibited the ability to produce strong year classes when climatic conditions are favorable such that the continued judicious use of artificially propagated predators seems necessary to avoid domination by alewife. It should be noted that this is not an option in Lake Superior because lake trout and salmon are almost entirely lake-produced. Potential bottom-up effects on preyfishes would be difficult to mitigate owing to our inability to affect changes. This scenario only reinforces the need to avoid further introductions of exotics into the Great Lake ecosystems.

Comments from the author(s)
It has been proposed that in order to restore an ecologically balanced fish community, a diversity of prey species at population levels matched to primary production and predator demands must be maintained. However, the current mix of native and naturalized prey and predator species, and the contributions of artificially propagated predator species into the system confound any sense of balance in lakes other than Superior. The metrics of ecological balance as the consequence of fish community structure are best defined through food-web interactions. It is through understanding the exchanges of trophic supply and demand that the fish community can be described quantitatively and ecological attributes such as balance can be better defined and the limits inherent to the ecosystem realized.

Continued monitoring of the fish communities and regular assessments of food habits of predators and preyfish will be required to quantify the food-web dynamics in the Great Lakes. This recommendation is especially supported by continued changes that are occurring not only in the upper but also in the lower trophic levels. Recognized sampling limitations of traditional capture techniques (bottom trawling) have prompted the application of acoustic techniques as another means to estimate absolute abundance of preyfishes in the Great Lakes. Though not an assessment panacea, hydro-acoustics have provided additional insights and have demonstrated utility in the estimates of preyfish biomass.

Protecting or reestablishing rare or extirpated members of the once prominent native preyfishes, most notably the various members of the whitefish family (*Coregonus* spp.), should be a priority in all the Great Lakes but especially in Lake Ontario where vast areas of the lake once occupied by extirpated deepwater ciscoes are devoid of fish for much of the year. This recommendation should be reflected in future indicator reports. Lake Superior, whose preyfish assemblage is dominated by indigenous species and retains a full complement of ciscoes, should be examined more closely to better understand the trophic ecology of its more natural system.

With the continuous nature of changes that seems to characterize the preyfishes, and the lower trophic levels on which they depend, the appropriate frequency to review this indicator is on a 5-year basis.

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Figure 1. Preyfish trends based on annual bottom trawl surveys. All trawl surveys were performed by USGS - Great Lakes Science Center, except for Lake Erie, which was conducted by the USGS, Ohio Division of Wildlife and the Ontario Ministry of Natural Resources (Lake Erie Forage Task Group), and Lake Ontario, which was conducted jointly by USGS and the New York State Department of Environmental Conservation.

Sources: U.S. Geological Survey - Great Lakes Science Center, Ohio Division of Wildlife, Ontario Ministry of Natural Resources, and New York State Department of Environmental Conservation.

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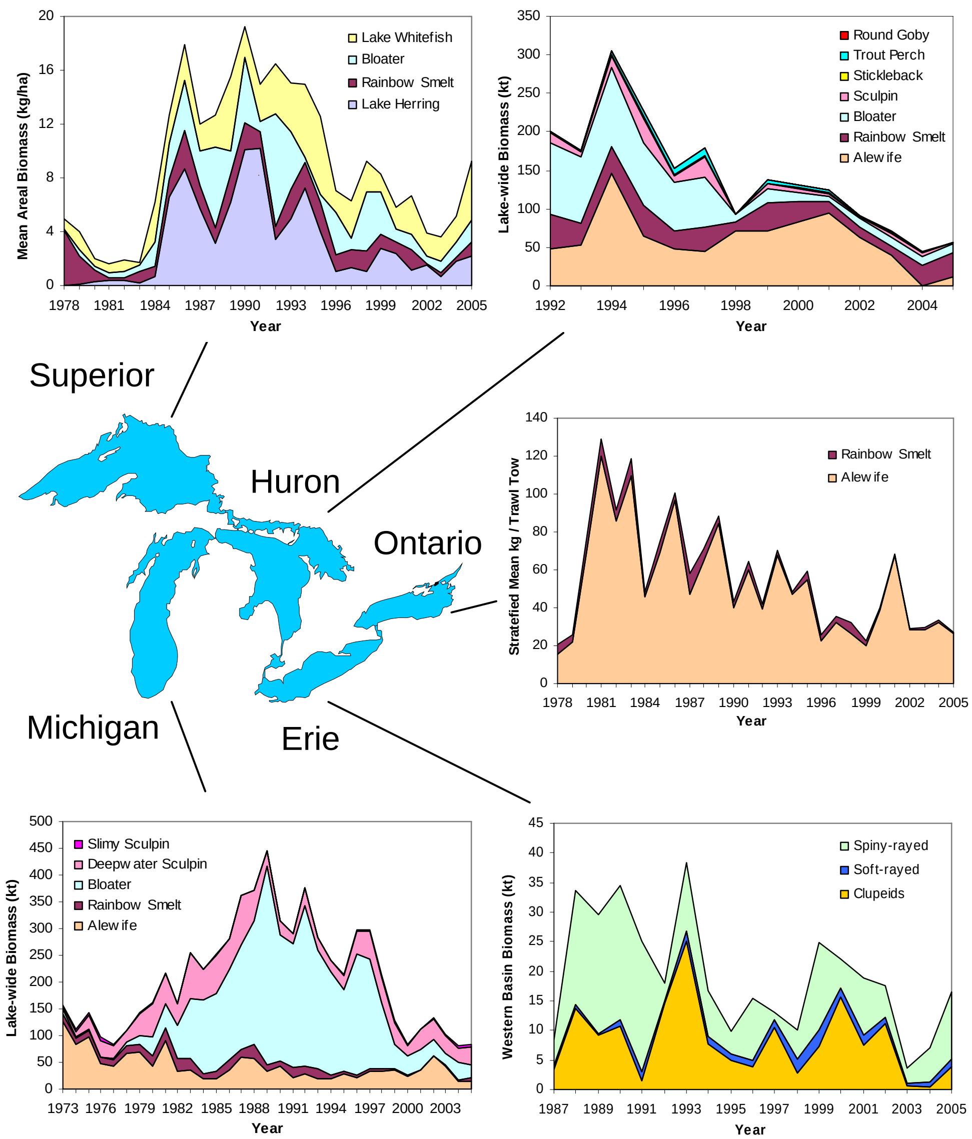

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Sources: U.S. Geological Survey - Great Lakes Science Center, Ohio Division of Wildlife, Ontario Ministry of Natural Resources, and New York State Department of Environmental Conservation.

Sea Lamprey

Indicator #18

Assessment: Good/Fair, Improving

Purpose

- To estimate the abundance of sea lamprey as an indicator of the status of this invasive species; and
- To infer the damage sea lamprey cause to the fish communities and aquatic ecosystems of the Great Lakes.

Ecosystem Objective

The 1955 Convention of Great Lakes Fisheries created the Great Lakes Fishery Commission (GLFC) "*to formulate and implement a comprehensive program for the purpose of eradicating or minimizing the sea lamprey populations in the Convention area*" (GLFC 1955). Under the Joint Strategic Plan for Great Lakes Fisheries, all fishery management agencies established Fish Community Objectives (FCOs) for each of the lakes. These FCOs call for suppressing sea lamprey populations to levels that cause only insignificant mortality of fish in order to achieve objectives for lake trout and other members of the fish community (Horns *et al.* 2003, Eshenroder *et al*. 1995, DesJardin *et al.* 1995, Ryan *et al.* 2003., Stewart *et al***.** 1999).

The GLFC and fishery management agencies have agreed on target abundance levels for sea lamprey populations that correspond to the FCOs (Table 1). Targets were derived from available estimates of the abundance of spawning-phase sea lampreys and from data on wounding rates on lake trout. Suppressing sea lampreys to abundances within the target range is predicted to result in tolerable mortality on lake trout and other fish species.

Lake	FCO Sea Lamprey Abundance Targets	Target Range (+/- 95% Confidence Interval)
Superior	35,000	18,000
Michigan	58,000	13,000
Huron	74,000	20,000
Erie	3,000	1,000
Ontario	29,000	4,000

Table 1. Fish Community Objectives for sea lamprey abundance targets.
Source: Great Lakes Fishery Commission

State of the Ecosystem

<u>Background</u>

Populations of the native top predator, lake trout, and other fishes are negatively affected by mortality caused by sea lamprey. The first complete round of stream treatments with the lampricide TFM, as early as 1960 in Lake Superior, successfully suppressed sea lamprey to less than 10% of their pre-control abundance in all of the Great Lakes.

Mark and recapture estimates of the abundance of sea lamprey migrating up rivers to spawn are used as surrogates for the abundance of parasites feeding in the lakes during the previous year. Estimates of individual spawning runs in trappable streams are used to estimate lake-wide abundance using a new regression model that relates run size to stream characteristics (Mullett *et al*. 2003). Sea lamprey spend one year in the lake after metamorphosing, so this indicator has a two-year lag in demonstrating the effects of control efforts.

<u>Status of Sea Lamprey</u>

Annual lake-wide estimates of sea lamprey abundance since 1980, with 95% confidence intervals, are presented in Figure 1. The FCO targets and ranges also are included for each lake.

Lake Superior: During the past 20 years, populations have fluctuated but remain at levels less than 10% of peak abundance (Heinrich *et al. 2003*). Abundances were within the FCO target range during the late 1980s and mid-1990s. Abundances have trended upward from a low during 1994 and have been above the target range from 1999-2003. These recent increases in abundance have raised concern in all waters. Rates of sea lamprey markings on fish have shown the same pattern of increase. These increases appear to be most dramatic in the Nipigon Bay and north-western portion of the lake and in the Whitefish Bay area in the south-eastern portion of the lake. Survival objectives for lake trout continue to be met but lake trout populations could be threatened if these increases continue. In response to this increased abundance of sea lampreys, stream treatments with lampricides were increased beginning in 2001 through 2004. The effects of the increased treatments during 2001 may have contributed to the downward trend in the 2003 observation. The effects of additional stream treatments in 2002 and beyond will be observed in the spawning-run estimates during 2004 and following years.

Lake Michigan: The population of sea lamprey has shown a continuing, slow trend upward since 1980 (Lavis *et al*. 2003). The population was at or below the FCO target range until 2000. The marking rates on lake trout have shown the same upward trend past target levels during the recent years. Increases in abundance during the 1990s had been attributed to the St. Marys River. The continuing trend in recent years suggests sources of sea lamprey in Lake Michigan itself. Stream treatments were increased beginning in 2001 through 2004. This increase included treatment of newly discovered populations in lentic areas and treatment of the Manistique River, a large system where the deterioration of a dam near the mouth allowed sea lamprey access to nursery habitat. The 2003 spawning-phase population estimate did not show any decrease as a result of the increased treatments during 2001.

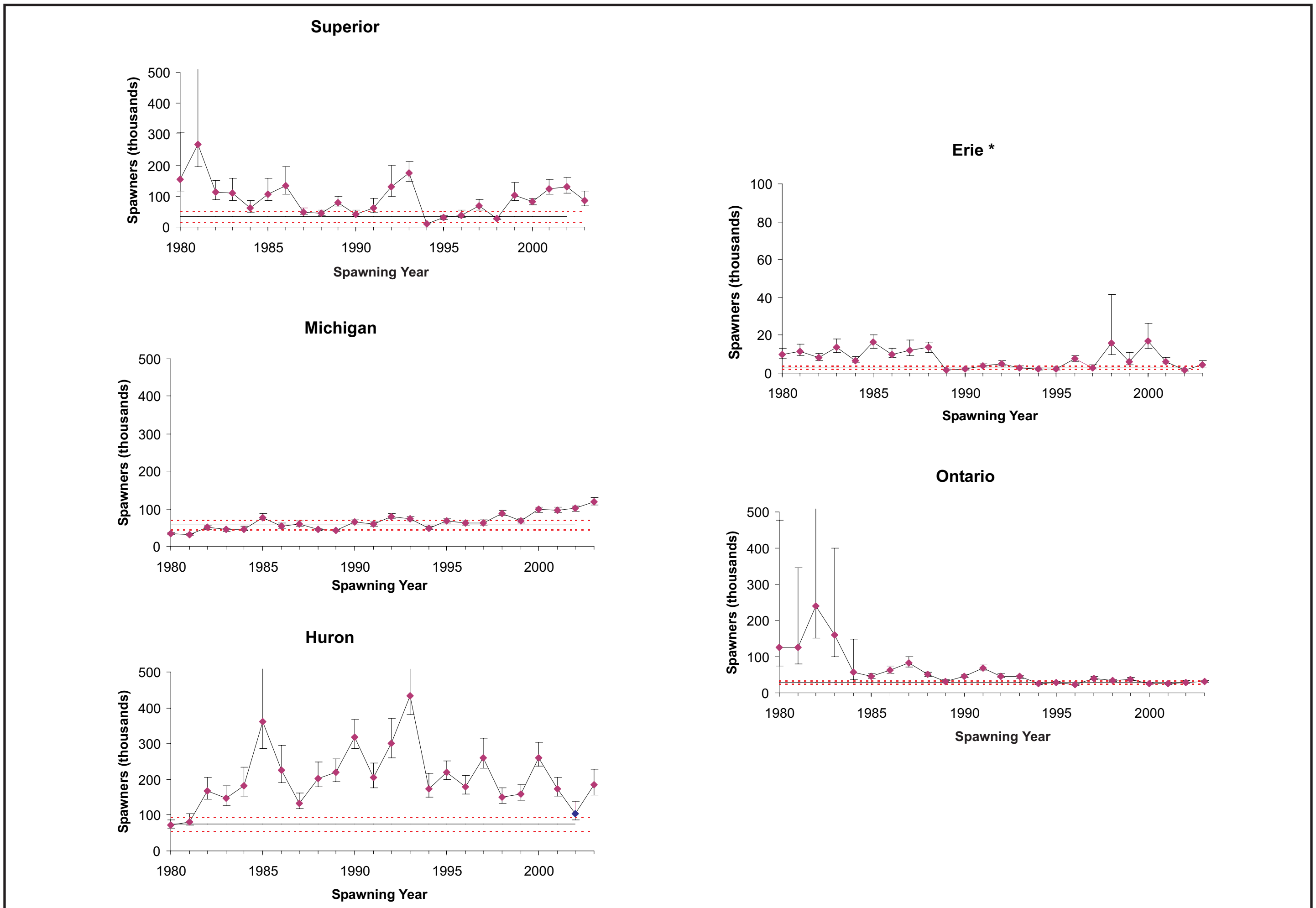

Figure 1. Total abundance of sea lampreys estimated during the spawning migration. Solid line and dashed line represent FCO target abundance and ranges, respectively.
*Note: the scale for Lake Erie is 1/5 that of the other four Lakes.
Source: Great Lakes Fishery Commission

Lake Huron: The first full round of stream treatments during the late 1960s suppressed sea lamprey populations to levels less than 10% of those before control (Morse *et al.* 2003). During the early 1980s, abundance increased in Lake Huron, particularly the northern portion of the lake, peaking in 1993. Through the 1990s there were more sea lampreys in Lake Huron than all the other lakes combined. FCOs were not being achieved. The damage caused by this large population of parasites was so severe that the Lake Huron Committee abandoned its lake trout restoration objective in the northern portion of the lake during 1995. The St. Marys River was identified as the source of the increasing sea lamprey population. The size of this connecting channel made traditional treatment with the lampricide TFM impractical. A new integrated control strategy, including targeted application of a new formulation of a bottom-release lampricide, enhanced trapping of spawning animals, and sterile-male release, was initiated in 1997 (Schleen *et al.* 2003). As predicted, the spawning-phase abundance has been significantly lower since 2001 as a result of the completion of the first full round of lampricide spot treatments during 1999. However, the population shows considerable variation and it increased during 2003. Wounding rates and mortality estimates for lake trout have also declined during the last three years. The full effect of the St. Marys River control program will not be observed for another 2-4 years (Adams *et al.* 2003). The GLFC has repeated lampricide treatments in limited areas with high densities of larvae during 2003 and 2004. These additional treatments are aimed at continuing the decline in sea lamprey in Lake Huron.

Lake Erie: Following the completion of the first full round of stream treatments in 1987, sea lamprey populations collapsed (Sullivan *et al.* 2003). Marking rates on lake trout declined and lake trout survival increased to levels sufficient to meet the rehabilitation objectives in the eastern basin. However, during the mid-1990s, sea lamprey abundance increased to levels that threatened the lake trout restoration effort. A major assessment effort during 1998 indicated that the source of this increase was several streams in which treatments had been deferred due to low water flows or concerns for non-target organisms. These critical streams were treated during 1999 and 2000. Sea lamprey abundance was observed to decline to target levels in 2001 through 2003. Wounding rates on lake trout have also declined.

Lake Ontario: Abundance of spawning-phase sea lamprey has shown a continuing declining trend since the early 1980s (Larson *et al.* 2003). The abundance of sea lamprey has remained stable in the FCO target range during 2000-2003.

Pressures

Since parasitic-phase sea lamprey are at the top of the aquatic food chain and inflict high mortality on large piscivores, population control is essential for healthy fish communities. Increasing abundance in Lake Erie demonstrates how short lapses in control can result in rapid increases in abundance and that continued effective stream treatments are necessary to overcome the reproductive potential of this invading species. The potential for sea lamprey to colonize new locations is increased with improved water quality and removal of dams. For example, the loss of integrity of the dam on the Manistique River, and subsequent production from this river, has contributed to the increase in sea lamprey abundance in Lake Michigan. Any areas newly infested with sea lamprey will require some form of control to attain target abundance levels in the lakes.

As fish communities recover from the effects of sea lamprey predation or over-fishing, there is evidence that the survival of parasitic sea lamprey may increase due to prey availability. Better survival means that there will be more residual sea lamprey to cause harm. Significant additional control efforts, like those on the St. Marys River, may be necessary to maintain suppression.

The GLFC has a goal of reducing reliance on lampricides and increasing efforts to integrate other control techniques, such as the sterile-male-release technique or the installation of barriers to stop the upstream migration of adults. Pheromones that affect migration and mating have been discovered and offer exciting potential as new alternative controls. The use of alternative controls is consistent with sound practices of integrated pest management, but can put additional pressures on the ecosystem such as limiting the passage of fish upstream of barriers. Care must be taken in applying new alternatives or in reducing lampricide use to not allow sea lamprey abundance to increase.

Management Implications

The GLFC has increased stream treatments and lampricide applications in response to increasing abundances during 2001 through 2004. The GLFC has targeted these additional treatments to maximize progress toward FCO targets. The GLFC continues to focus on research and development of alternative control strategies. Computer models, driven by empirical data, are being used to best allocate treatment resources, and research is being conducted to better understand and manage the variability in sea lamprey populations.

Acknowledgments

Author: Gavin Christie, Great Lakes Fishery Commission, Ann Arbor, MI.

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Authors' Commentary

Targeted increases in lampricide treatments are predicted to reduce sea lamprey abundance to acceptable levels. The effects of increased treatments will be observed in this indicator two years after they occur. Discrepancies among estimates of different life-history stages need to be resolved. Efforts to identify all sources of sea lamprey need to continue. In addition, research to better understand lamprey/prey interactions, the population dynamics of sea lamprey that survive control actions, and refinement of alternative control methods are all key to maintaining sea lamprey at tolerable levels.

Last Updated

State of the Great Lakes 2005

Native Freshwater Mussels

Indicator #68

Assessment: Not Assessed

Purpose

- To assess the location and status of freshwater mussel (unionid) populations and their habitats throughout the Great Lakes system, with emphasis on endangered and threatened species; and
- To use this information to direct research aimed at identifying the factors responsible for mussel survival in refuge areas, which in turn will be used to predict the locations of other natural sanctuaries and guide their management for the protection and restoration of Great Lakes mussels.

Ecosystem Objective

The objective is the restoration of the richness, distribution, and abundance of mussels throughout the Great Lakes, which would thereby reflect the general health of the basin ecosystems. The long-term goal is for mussel populations to be stable and self-sustaining wherever possible throughout their historical range in the Great Lakes, including the connecting channels and tributaries.

State of the Ecosystem

Background

Freshwater mussels (*Bivalvia: Unionacea*) are of unique ecological value as natural biological filters, food for fish and wildlife, and indicators of good water quality. In the United States, some species are commercially harvested for their shells and pearls. These slow-growing, long-lived organisms can influence ecosystem function such as phytoplankton ecology, water quality, and nutrient cycling. As our largest freshwater invertebrate, freshwater mussels may also constitute a significant proportion of the freshwater invertebrate biomass where they occur. Because they are sensitive to toxic chemicals, mussels may serve as an early-warning system to alert us of water quality problems. They are also good indicators of environmental change due to their longevity and sedentary nature. Since mussels are parasitic on fish during their larval stage, they depend on healthy fish communities for their survival.

The richness, distribution, and abundance of mussels reflect the general health of the aquatic ecosystems. Because their shells are attractive and easy to find, they were prized by amateur collectors and naturalists in the past. As a result, many museums have extensive shell collections dating back 150 years or more that provide us with an invaluable "window to the past" that is not available for other aquatic invertebrates.

Status of freshwater mussels

The abundance and number of species of freshwater mussels have severely declined across North America, particularly in the Great Lakes. Nearly 72% of the 300 species in North America are vulnerable to extinction or already extinct. The decline of unionids has been attributed to commercial exploitation, water quality degradation (pollution, siltation), habitat destruction (dams, dredging, channelization) riparian and wetland alterations, changes in the distribution and/or abundance of host fishes, and competition with non-native species. In the Great Lakes watershed, zebra mussels (*Dreissena polymorpha*) and, to a lesser extent, quagga mussels (*D. bugensis*) have caused a severe decline in unionid populations. Zebra mussels attach to a mussel's shell, where they interfere with activities such as feeding, respiration and locomotion - effectively robbing it of the energy reserves needed for survival and reproduction. Native mussels are particularly sensitive to biofouling by zebra mussels and to food competition with both zebra mussel and quagga mussels.

Many areas in the Great Lakes, such as Lake St. Clair and Lake Erie, have lost over 99% of their native mussels of all species as a result of the impacts of dreissenids. Although Lake Erie, Lake St. Clair, and their connecting channels historically supported a rich mussel fauna of about 35 species, unionid mussels were slowly declining in some areas even before the zebra mussel invasion. For example, densities in the western basin of Lake Erie decreased from 10 unionids/m^2 in 1961 to 4/m^2 in 1982, probably due to poor water quality. In contrast, the impact of the zebra mussel was swift and severe. Unionids were virtually extirpated from the offshore waters of western Lake Erie by 1990 and from Lake St. Clair by 1994, with similar declines in the connecting channels and many nearshore habitats. The average number of unionid species found in these areas before the zebra mussel invasion was 18 (Figure 1). After the invasion, 60% of surveyed sites had 3 or fewer species remaining, 40% of sites had none left, and abundance had declined by 90-95%.

It was feared that unionid mussels would be extirpated from Great Lakes waters by the zebra mussel. However, significant communities were recently discovered in several nearshore areas where zebra mussel infestation rates are low (Figure 1).

These remnant unionid populations, found in isolated habitats such as river mouths and lake-connected wetlands, are at severe risk. Reproduction is occurring at some of these sites, but not all. Further problems are associated with unionid species that were in low numbers before the influx of the non-native dreissenids. A number of species that are listed as endangered or threatened in the United States or Canada are found in some of these isolated populations in the Great Lakes and in associated tributaries. In the United States, these include the clubshell (*Pleurobema clava*), fat pocketbook (*Potamilus capax*), northern riffleshell

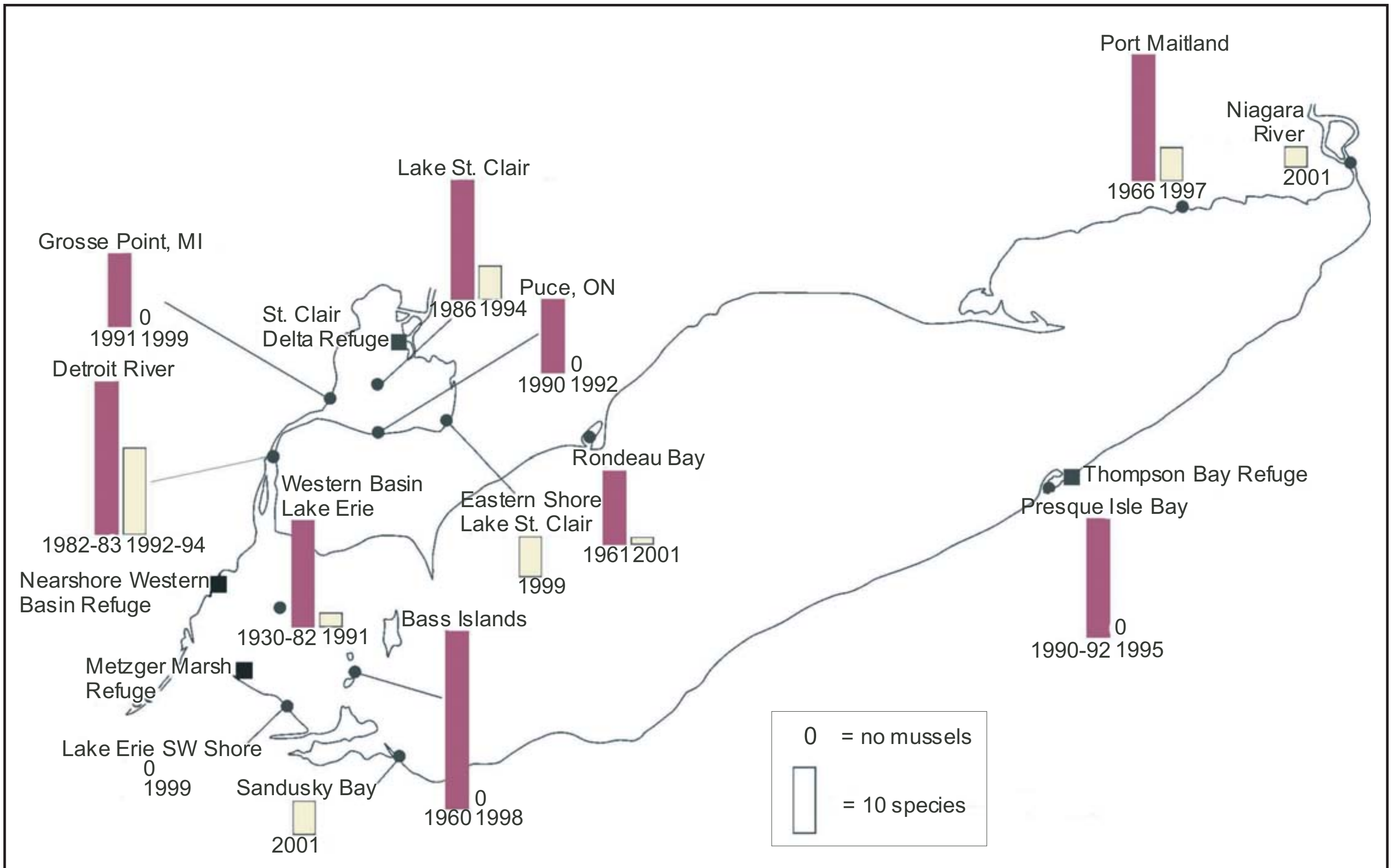

Figure 1. Numbers of freshwater mussel species found before and after the zebra mussel invasion at 13 sites in Lake Erie, Lake St. Clair, and the Niagara and Detroit Rivers (no "before" data available for 4 sites), and the locations of the four known refuge sites (Thompson Bay, Metzger Marsh, Nearshore Western Basin, and St. Clair Delta).
Source: Metcalfe-Smith, J.L., D.T. Zanatta, E.C. Masteller, H.L. Dunn, S.J. Nichols, P.J. Marangelo, and D.W. Schloesser. 2002

(*Epioblasma torulosa rangiana*), and white catspaw (*Epioblasma obliquata perobliqua*). In Canada, the northern riffleshell, rayed bean (*Villosa fabalis*), wavyrayed lampmussel (*Lampsilis fasciola*), salamander mussel (*Simpsonaias ambigua*), snuffbox (*Epioblasma triquetra*), round hickorynut (*Obovaria subrotunda*), kidneyshell (*Ptychobranchus fasciolaris*) and round pigtoe (*Pleurobema sintoxia*) are listed as endangered.

All of the refuge sites discovered to date have two characteristics in common: they are very shallow (<1-2 m deep), and they have a high degree of connectivity to the lake, which ensures access to host fishes. These features appear to combine with other factors to discourage the settlement and survival of zebra mussels. Soft, silty substrates and high summer water temperatures in Metzger Marsh, Thompson Bay and Crane Creek encourage unionids to burrow, which dislodges and suffocates attached zebra mussels. Unionids living in firm, sandy substrates at the nearshore western basin site were nearly infestation-free. The few zebra mussels found were less than 2 years old, suggesting that they may be voluntarily releasing from unionids due to harsh conditions created by wave action, fluctuating water levels and ice scour. The St. Clair Delta site has both wave-washed sand flats and wetland areas with soft, muddy sediments. It is thought that the numbers of zebra mussel veligers (planktonic larval stage) reaching the area may vary from year to year, depending on wind and current direction and water levels.

Since the veligers require an average of 20-30 days to develop into the benthic stage, rivers and streams have limited colonization potential and can provide natural refugia for unionids. However, regulated rivers, i.e., those with reservoirs, may not provide refugia. Reservoirs with retention times greater than 20-30 days will allow veligers to develop and settle, after which the impounded populations will seed downstream reaches on an annual basis. It is therefore vital to prevent the introduction of zebra mussels into reservoirs.

Pressures
Zebra mussel expansion is the main threat facing unionids in the Great Lakes drainage basin. Zebra mussels are now found in all of the Great Lakes and in many associated water bodies, including at least 260 inland lakes and river systems such as the Rideau River in Ontario and in two reservoirs in the Thames River drainage in Ontario.

Other non-native species may also impact unionid survival through the reduction or redistribution of native fishes. Non-native fish species such as the Eurasian ruffe (*Gymnocephalus cernuus*) and round goby (*Neogobius melanostomus*) can completely displace native fish, thus causing the functional extirpation of local unionid populations.

Continuing changes in land use (increasing urban sprawl, growth of factory farms, etc.), elevated use of herbicides to remove aquatic vegetation from lakes for recreational purposes, climate change and the associated lowering of water levels, and many other factors will continue to have an impact on unionid populations in the future.

Management Implications
The long-term goal is for unionid mussel populations to be stable and self-sustaining wherever possible throughout their historical range in the Great Lakes, including the connecting channels and tributaries. The most urgent activity is to prevent the further introduction of non-native species into the Great Lakes. A second critical activity is to prevent the further expansion of non-native species into the river systems and inland lakes of the region where they may seriously harm the remaining healthy populations of unionids that could be used to re-inoculate the Great Lakes themselves in the future.

To ensure the survival of remaining unionids in the Great Lakes basin, and to foster the restoration of their populations to the extent possible, the following actions are recommended:

- All existing information on the status of freshwater mussels throughout the Great Lakes drainage basin should be compiled and reviewed. A complete analysis of trends over space and time is needed to properly assess the current health of the fauna.

- To assist with the above exercise, and to guide future surveys, all data must be combined into a computerized, GIS-linked database (similar to the 8000-record Ontario database managed by the National Water Research Institute), accessible to all relevant jurisdictions.

- Additional surveys are needed to fill data gaps, using standardized sampling designs and methods for optimum comparability of data. The Freshwater Mollusk Conservation Society has prepared a peer-reviewed, state-of-the art protocol that should be consulted for guidance (Strayer and Smith 2003). Populations of endangered and threatened species should be specifically targeted.

- The locations of all existing refugia, both within and outside of the influence of zebra mussels, should be documented, and they must be protected by all possible means from future disturbance.

- Research is needed to determine the mechanisms responsible for survival of unionids in the various refuge sites, and this knowledge should be used to predict the locations of other refugia and to guide their management.

- The environmental requirements of unionids need to be taken into account in wetland restoration projects.

- All avenues for educating the public about the plight of unionids in the Great Lakes should be pursued, as well as legislation for their protection. This includes ensuring that all species that should be listed are listed as quickly as possible.

- The principles of the National Strategy for the Conservation of Native Freshwater Mussels (The National Native Mussel Conservation Committee 1998) should be applied to the conservation and protection of the Great Lakes unionid fauna.

Acknowledgments
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Last Updated
State of the Great Lakes 2005

Lake Trout
Indicator #93

Overall Assessment

Status: **Mixed**
Trend: **Unchanging**

Lake-by-Lake Assessment

Lake Superior

Status: Good
Trend: Improving

Lake Michigan

Status: Poor
Trend: Declining

Lake Huron

Status: Mixed
Trend: Improving

Lake Erie

Status: Mixed
Trend: Unchanging

Lake Ontario

Status: Mixed
Trend: Declining

Purpose

•To track the status and trends in lake trout populations; and
•To infer the basic structure of the cold water predator community and the general health of the ecosystem.

Ecosystem Objective

Self-sustaining, naturally reproducing populations that support target yields to fisheries are the goal of the lake trout restoration program. Target yields approximate historical levels of lake trout harvest or levels adjusted to accommodate stocked non-native predators such as Pacific salmon. These targets are 4 million pounds (1.8 million kg) from Lake Superior, 2.5 million pounds (1.1 million kg) from Lake Michigan, 2.0 million pounds (0.9 million kg) from Lake Huron and 0.1 million pounds (0.05 million kg) from Lake Erie. Lake Ontario has no specific yield objective but has a population objective of 0.5-1.0 million adult fish that produce 100,000 yearling recruits annually through natural reproduction.

State of the Ecosystem

Background

Lake trout were historically the principal salmonine predator in the coldwater communities of the Great Lakes. By the late 1950s, lake trout were extirpated throughout most of the Great Lakes mostly from the combined effects of sea lamprey predation and over fishing. Restoration efforts began in the early 1960s with chemical control of sea lamprey, controls on exploitation, and stocking of hatchery-reared fish to rebuild populations. Full restoration will not be achieved until natural reproduction is established and maintained to sustain lakewide populations. To date, only Lake Superior has that distinction.

Status of Lake Trout

Trends in the relative or absolute annual abundance of lake trout in each of the Great Lakes are displayed in Figure 1. Lake trout abundance dramatically increased in all the Great Lakes after initiation of sea lamprey control, stocking, and harvest control. Natural reproduction, from large parental stocks of wild fish is occurring throughout Lake Superior, supports both onshore and offshore populations, and it may be approaching historical levels. Stocking there has been discontinued. Sustained natural reproduction, albeit at low levels, has also been occurring in Lake Ontario since the early 1990s, and in some areas of Lake Huron, but has been largely absent elsewhere in the Great Lakes. In Lake Huron substantial and widespread natural reproduction was seen starting in 2004 following near collapse of alewife populations. Abundance of hatchery-reared adults was relatively high in Lake Ontario from 1986 – 1998, but declined by more than 30% in 1999 due to reduced stocking and poor survival of stocked yearlings since the early 1990s. Adult abundance again declined by 54% in 2006 likely due to ongoing poor recruitment and mortality from sea lamprey predation. Parental stock sizes of hatchery-reared fish were relatively high in some areas of Lakes Huron and Michigan, but sea lamprey predation, fishery extractions, and low stocking densities have limited population expansion elsewhere.

Pressures

Sea lamprey continues to limit population recovery, particularly in Lakes Michigan and Superior, and parasitic adults are increasing basin-wide. Fishing pressures also continue to limit recovery. More stringent controls on fisheries are required to increase survival of stocked fish. In northern Lake Michigan parental stock sizes are low and young in age due to low stocking densities, moderate fishing mortality, and substantial sea lamprey mortality; hence egg deposition is low in most historically important spawning areas. Fishing mortality has been reduced in recent years but replaced by sea lamprey mortality. High biomass of alewives and predators on lake trout spawning reefs are thought to inhibit restoration through egg and fry predation, although the magnitude of this pressure is unclear. Recent trends in Lake Huron suggest that alewife may need to reach very low abundances to allow substantial natural reproduction. A diet dominated by alewives may be limiting fry survival (early mortality syndrome) through thiamine deficiencies. The loss of *Diporeia* and dramatic reductions in the abundance of slimy sculpins is reducing prey for young lake trout and may be affecting survival. Current strains of lake trout stocked may not be appropriate for offshore habitats, therefore limiting colonization potential.

Management Implications

Continued and enhanced sea lamprey control is required basin-wide to increase survival of lake trout to adulthood. New sea lamprey control options, which include pheromone systems that increase trapping efficiency and disrupt reproduction, are being researched and hold promise for improved control. Continued and enhanced control on exploitation is being improved through population modeling in the upper Great Lakes but needs to be applied throughout the basin. Stocking densities need to be increased in some areas, especially in Lake Michigan. The use of alternate strains of lake trout from Lake Superior could be candidates for deep, offshore areas not colonized by traditional strains used for restoration. Introduction of such strains has been initiated in Lake Erie and hold promise. Direct stocking of eggs, fry, and yearling on or near traditional spawning sites should be used where possible to enhance colonization.

Comments from the author(s)
Reporting frequency should be every 5 years. Monitoring systems are in place, but in most lakes measures do not directly relate to stated harvest objectives. Population objectives may need to be redefined as endpoints in units measured by the monitoring activities.

Acknowledgments
Authors: Charles R. Bronte, U.S. Fish and Wildlife Service, New Franken, WI;
James Markham, New York Department of Environmental Conservation;
Brian Lantry, U.S. Geological Survey, Oswego, NY;
Aaron Woldt, U.S. Fish and Wildlife Service, Alpena, MI; and
James Bence, Michigan State University, East Lansing, MI.

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Figure 1. Relative or absolute abundance of lake trout in the Great Lakes. The measurement reported varies from lake to lake, as shown on the vertical scale, and comparisons between lakes may be misleading. Overall trends over time provide information on relative abundances. Source: U.S. Fish and Wildlife Service

Last updated

SOLEC 2006

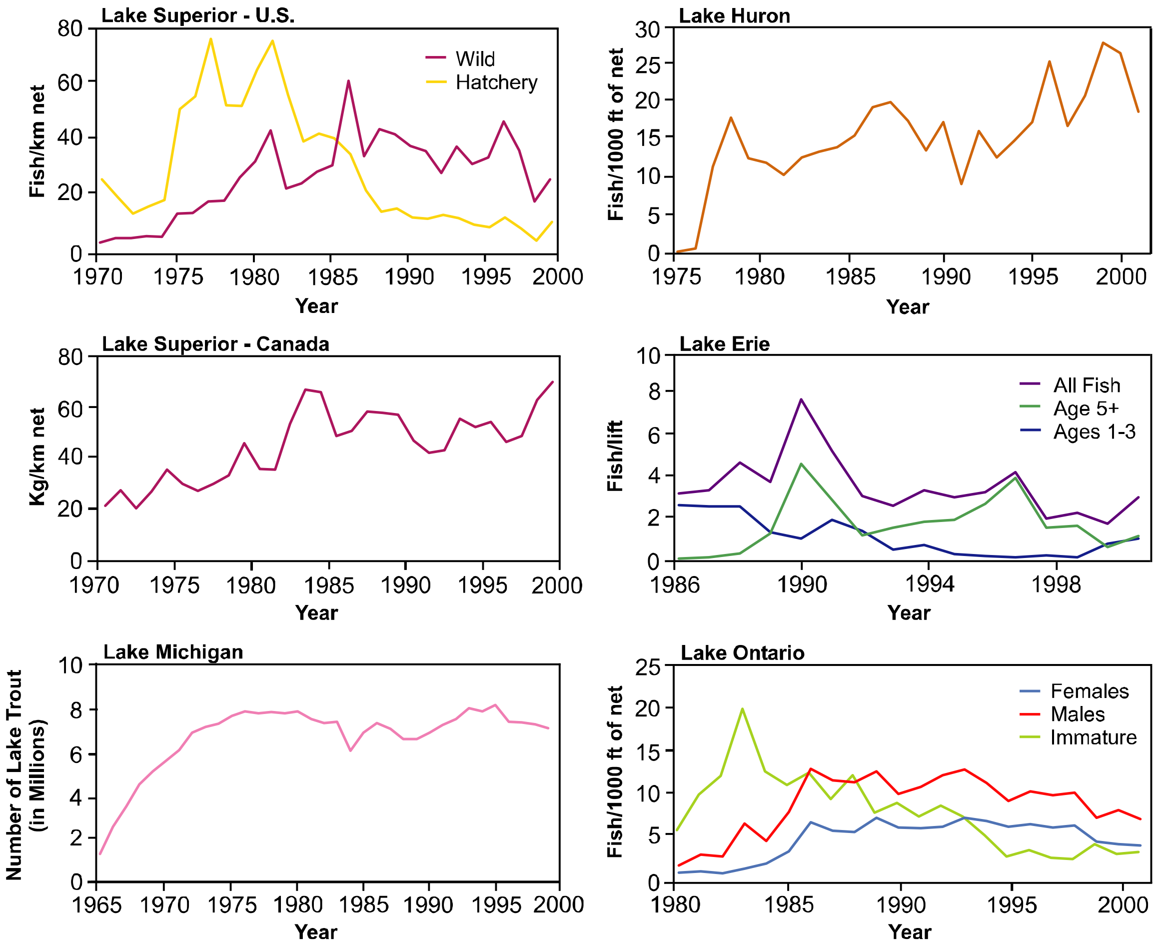

Figure 1. Relative or absolute abundance of lake trout in the Great Lakes. The measurement reported varies from lake to lake, as shown on the vertical scale, and comparisons between lakes may be misleading. Overall trends over time provide information on relative abundances. Source: U.S. Fish and Wildlife Service

Benthos Diversity and Abundance - Aquatic Oligochaete Communities

Indicator #104

Overall Assessment

Status:	Mixed
Trend:	Unchanging/ deteriorating
Primary Factors Determining Status and Trend	**Some lakes or parts of lakes are good and unchanging, while other lakes or parts of lakes are fair to poor and are either unchanging or may be deteriorating.**

Lake by Lake Assessment

Lake Superior

Status:	Good
Trend:	Unchanging
Primary Factors Determining Status and Trend	All sites had index values that ranged from 0 to <0.5, indicating oligotrophic conditions

Lake Michigan

Status:	Mixed
Trend:	Unchanging, Deteriorating
Primary Factors Determining Status and Trend	Most sites had index values that ranged from 0 to <0.5, indicating oligotrophic conditions. The two most southeastern, nearshore sites changed from oligotrophic status in 2000, mesotrophic status in 2001, mesotrophic/eutrophic status in 2002-2004, and back to mesotrophic in 2005. The most east-central, nearshore site changed from oligotrophic (2000-2004) to mesotrophic (2005).

Lake Huron

Status:	Mixed
Trend:	Unchanging
Primary Factors Determining Status and Trend	Saginaw Bay remained mesotrophic throughout the six years. All other sites were oligotrophic.

Lake Erie

Status:	Mixed
Trend:	Unchanging, Deteriorating
Primary Factors Determining Status and Trend	Most sites were mesotrophic to eutrophic. Two western sites were oligotrophic mesotrophic due to reduced numbers of oligochaetes. Eutrophic sites in the eastern part of the lake exhibited increasing index values.

Lake Ontario

Status:	Mixed
Trend:	Unchanging
Primary Factors	Most sites were oligotrophic. The three most southern, nearshore sites

Determining Status and Trend — varied from oligotrophic to eutrophic on a year to year basis.

Purpose
- To assess species diversity and abundance of aquatic oligochaete communities in order to determine the trophic status and relative health of benthic communities in the Great Lakes.

Ecosystem Objective
Benthic communities throughout the Great Lakes should retain species abundance and diversity typical for benthos in similar unimpaired waters and substrates. A measure of biological response to organic enrichment of sediments is based on Milbrink's (1983) Modified Environmental Index (MEI). This index was modified from Howmiller and Scott's (1977) Environmental Index. This measure will have wide application in nearshore, profundal, riverine, and bay habitats of the Great Lakes. This indicator supports Annex 2 of the Great Lakes Water Quality Agreement.

State of the Ecosystem
Shortly after intensive urbanization and industrialization during the first half of the 20th century, pollution abatement programs were initiated in the Great Lakes. Degraded waters and substrates, especially in shallow areas, began to slowly improve in quality. By the early 1980's, abatement programs and natural biological processes changed habitats to the point where aquatic species that were tolerant of heavy pollution began to be replaced by species that were intolerant of heavy pollution.

The use of Milbrink's index values to characterize aquatic oligochaete communities provided one of the earliest measures of habitat quality improvements (e.g., western Lake Erie). This index has been used to measure changing productivity in waters of North America and Europe and, in general, appears to be a reasonable measure of productivity in waters of all the Great Lakes (Figure 1). The index values from sites in the upper lakes continue to be very low (<0.6), indicating an oligotrophic status for these areas. Index values from sites such as the nearshore areas of southeastern and east-central Lake Michigan and Saginaw Bay in Lake Huron, which are known to have higher productivity, exhibited higher index values that indicate mesotrophic (0.6-1.0) to eutrophic (>1.0) conditions. Nearshore sites in southern Lake Ontario continued to be classified as mesotrophic to eutrophic, while offshore sites were oligotrophic. Sites in Lake Erie exhibited the highest index values; nearly all of them fell within the mesotrophic or eutrophic category (one site in western Lake Erie had low values characterized by low numbers of oligochaetes). Over the last six years, a trend of increasing index values was observed for eastern Lake Erie.

Pressures
Future pressures that may change suitability of habitat for aquatic oligochaete communities remain unknown. Pollution abatement programs and natural processes will assuredly continue to improve water and substrate quality. However, measurement of improvements could be overshadowed by pressures such as zebra and quagga mussels, which were an unknown impact only 10 years ago. Other possible pressures include non-point source pollution, regional temperature and water level changes, and discharges of contaminants such as pharmaceuticals, as

well as from other unforeseen sources.

Management Implications

Continued pollution abatement programs aimed at point source pollution will continue to reduce undesirable productivity and past residual pollutants. As a result, substrate quality will improve. Whatever future ecosystem changes occur in the Great Lakes, it is likely aquatic oligochaete communities will respond early to such changes.

Comments from the authors

Biological responses of aquatic oligochaete communities are excellent indicators of substrate quality, and when combined with a temporal component, they allow for the determination of subtle changes in environmental quality, possibly decades before single species indicators. However, it is only in the past several years that Milbrink's MEI has been applied to the open waters of all the Great Lakes. Therefore, it is critical that routine monitoring of oligochaete communities in the Great Lakes continue. Additionally, oligochaete taxonomy can be a specialized and time-consuming discipline, and the taxonomic classification of species and their responses to organic pollution is continually being updated. As future work progresses, it is anticipated that the ecological relevance of existing and new species comprising the index will increase. Modifications to this index must be incorporated in future work, which includes the assignment of index values to several taxa that are currently not included in the index, and the re-evaluation of index values for a few of the species that are included in the index. It should be noted that even though the index only addresses responses to organic enrichment in sediments, it may be used with other indicators to assess the effects of other sediment pollutants.

Acknowledgments

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Data Sources

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Figure 1. Scatter plots of index values for Milbrink's (1983) Modified Environmental Index, applied to data from GLNPO's 2000-2005 summer surveys. Values ranging from 0-0.6 indicate oligotrophic conditions; values from 0.6-1.0 indicate mesotrophic conditions (shaded area); values above 1.0 indicate eutrophic conditions. Index values for the taxa were taken from the literature (Milbrink 1983, Howmiller and Scott 1977); immature specimens were not included in

any calculations. Data points represent average of triplicate samples taken at each sampling site. Source: U.S. Environmental Protection Agency, 2000-2005.

Figure 2. Map of the Great Lakes showing trophic status based on Milbrink's (1983) Modified Environmental Index using the oligochaete worm community. Data taken from 2005. Gray circles = oligotrophic; yellow squares = mesotrophic; red triangles = eutrophic.

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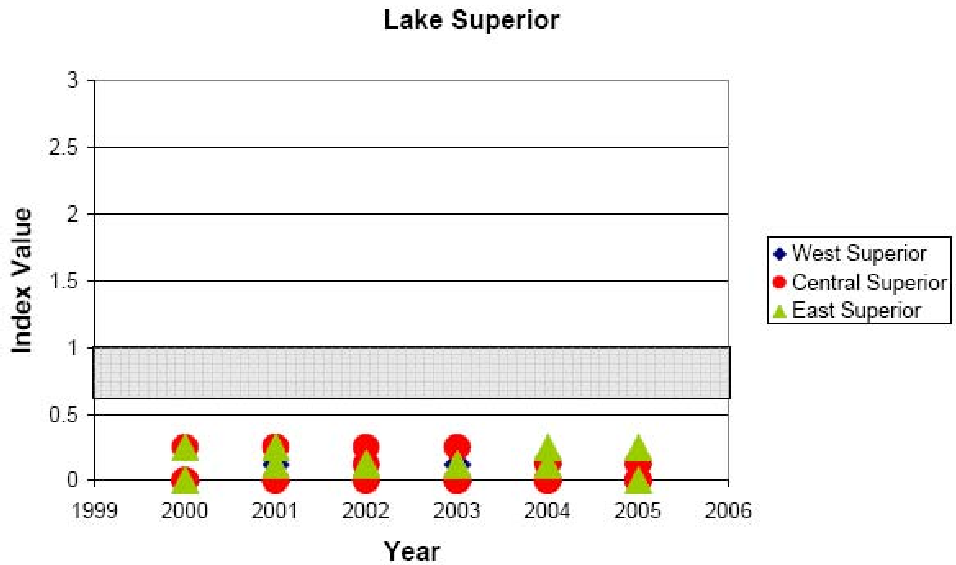
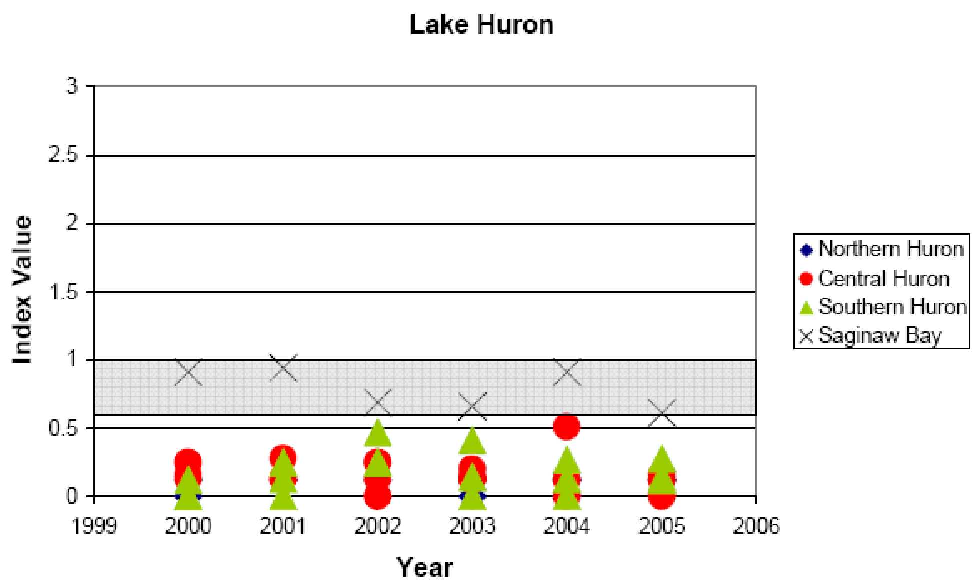
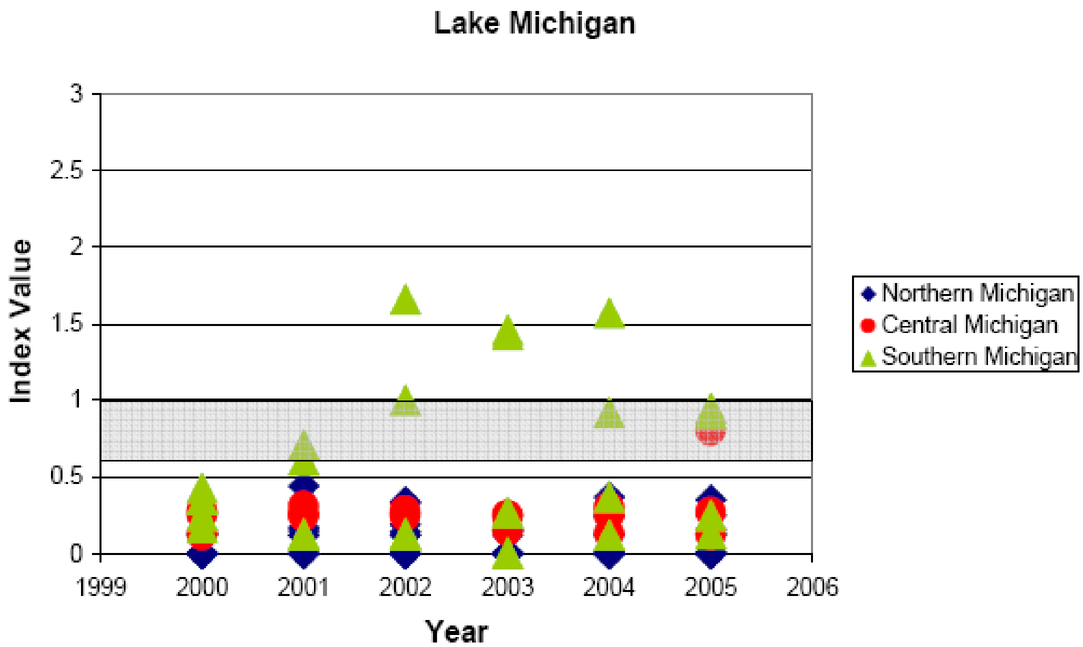
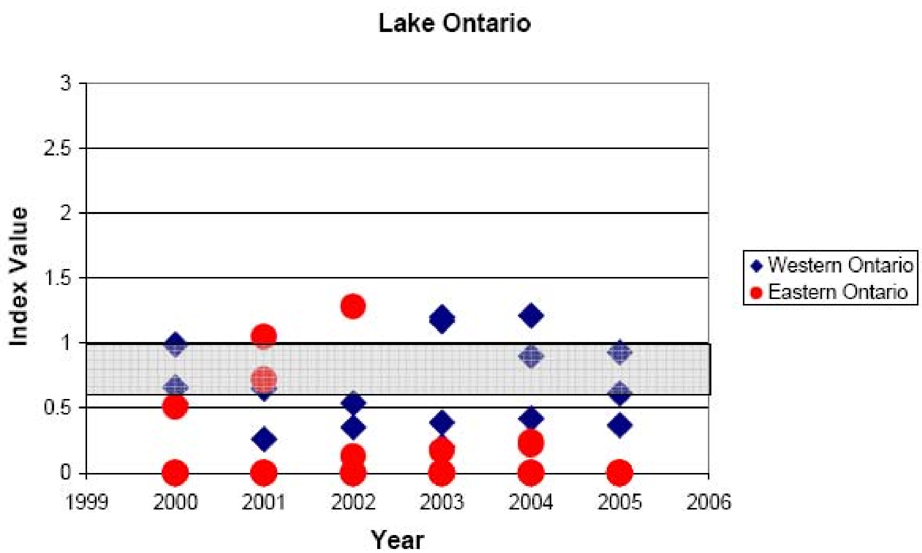
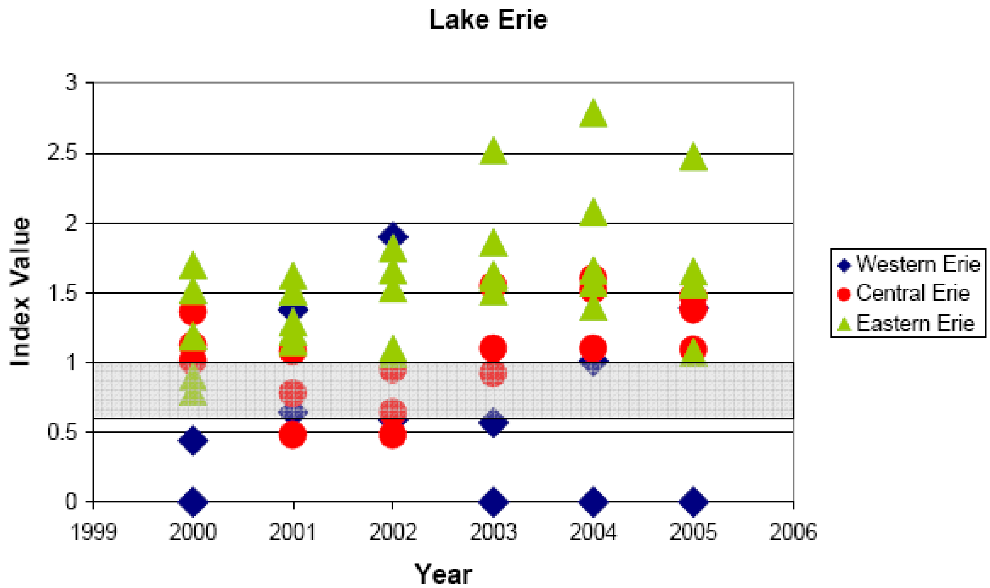





Lake Michigan
Index Value
3
2.5
2
1.5
1
0.5
0
1999
2000
2001
2002
2003
2004
2005
2006
Year
Northern Michigan
Central Michigan
Southern Michigan


Lake Ontario
Index Value
3
2.5
2
1.5
1
0.5
0
1999
2000
2001
2002
2003
2004
2005
2006
Year
Western Ontario
Eastern Ontario



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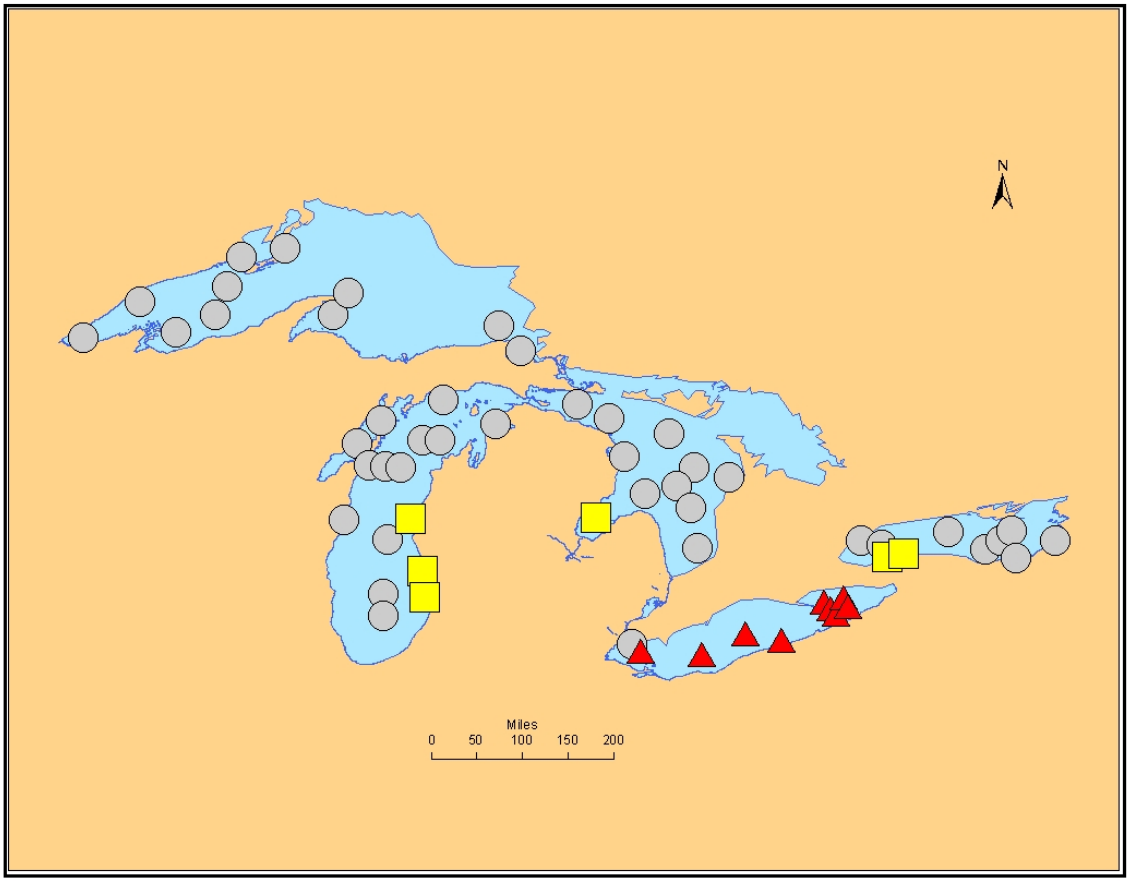

Figure 2. Map of the Great Lakes showing trophic status based on Milbrink's (1983) Modified Environmental Index using the oligochaete worm community. Data taken from 2005. Gray circles = oligotrophic; yellow squares = mesotrophic; red triangles = eutrophic.

Phytoplankton Populations

Indicator #109

Assessment: Mixed, Trend Not Assessed

This assessment is based on historical conditions and expert opinion. Specific objectives or criteria have not been determined.

Purpose

- To directly assess phytoplankton species composition, biomass, and primary productivity in the Great Lakes; and
- To indirectly assess the impact of nutrient and contaminant enrichment and invasive non-native predators on the microbial food-web of the Great Lakes.

Ecosystem Objective

Desired objectives are phytoplankton biomass size and structure indicative of oligotrophic conditions (i.e. a state of low biological productivity, as is generally found in the cold open waters of large lakes) for Lakes Superior, Huron and Michigan; and of mesotrophic conditions for Lakes Erie and Ontario. In addition, algal biomass should be maintained below that of a nuisance condition in Lakes Erie and Ontario, and in bays and in other areas wherever they occur. There are currently no guidelines in place to define what criteria should be used to assess whether or not these desired states have been achieved.

State of the Ecosystem

This indicator assumes that phytoplankton populations respond in quantifiable ways to anthropogenic inputs of both nutrients and contaminants, permitting inferences to be made about system perturbations through the assessment of phytoplankton community size, structure and productivity.

Records for Lake Erie indicate that substantial reductions in summer phytoplankton populations occurred in the early 1990s in the western basin (Figure 1). The timing of this decline suggests the possible impact of zebra mussels. In Lake Michigan, a significant increase in the size of summer diatom populations occurred during the 1990s. This was most likely due to the

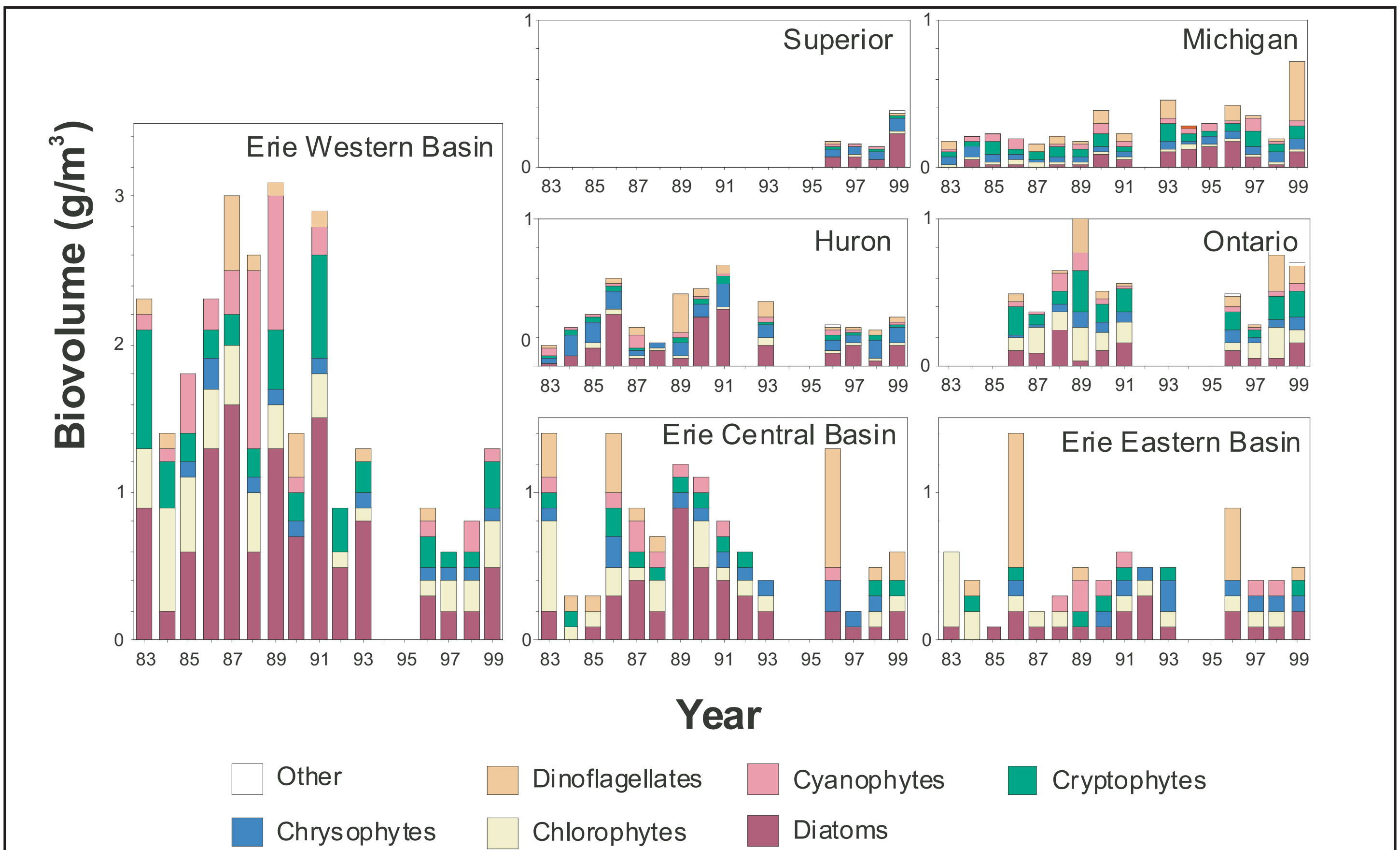

Figure 1. Trends in phytoplankton biovolume (g/m^3) and community composition in the Great Lakes 1983-1999. Samples were collected from offshore, surface waters during August.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office

effects of phosphorus reductions on the silica mass balance in this lake, and it suggests that diatom populations might be a sensitive indicator of oligotrophication in Lake Michigan. No trends are apparent in summer phytoplankton from Lakes Huron or Ontario, while only three years of data exist for Lake Superior. Data on primary productivity are no longer being collected. No assessment of “ecosystem health” is currently possible on the basis of phytoplankton community data, since reference criteria and endpoints have yet to be developed.

It should be noted that these findings are at variance with those reported for SOLEC 2000. This is due to problems with historical data comparability that were unrecognized during the previous reporting period. These problems continue to be worked on, and as such, conclusions reported here should be regarded as somewhat provisional.

Pressures
The two most important potential future pressures on the phytoplankton community are changes in nutrient loadings and continued introductions and expansions of non-native species. Increases in nutrients can be expected to result in increases in primary productivity and possibly also in increases in phytoplankton biomass. In addition, increases in phosphorus concentrations might result in shifts in phytoplankton community composition away from diatoms and towards other taxa. As seen in Lake Michigan, reductions in phosphorus loading might be expected to have the opposite effect. Continued expansion of zebra mussel populations might be expected to result in reductions in overall phytoplankton biomass, and perhaps also in a shift in species composition, although these potential effects are not clearly understood. It is unclear what effects, if any, might be brought about by changes in the zooplankton community.

Management Implications
The effects of increases in nutrient concentrations tend to become apparent in nearshore areas before offshore areas. The addition of nearshore monitoring to the existing offshore monitoring program might therefore be advisable. Given the greater heterogeneity of the nearshore environment, any such sampling program would need to be carefully thought out, and an adequate number of sampling stations included to enable trends to be discerned.

Acknowledgments
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Sources
U.S. Environmental Protection Agency, Great Lakes National Program Office. Unpublished data. Chicago, IL.

Authors’ Commentary
A highly detailed record of phytoplankton biomass and community structure has accumulated, and continues to be generated, through regular monitoring efforts. However, problems exist with internal comparability of this database. Efforts are currently underway to rectify this situation, and it is essential that the database continue to be refined and improved.

In spite of the existence of this database, its interpretation remains problematic. While the use of phytoplankton data to assess “ecosystem health” is conceptually attractive, there is currently no objective, quantitative mechanism for doing so. Reliance upon literature values for nutrient tolerances or indicator status of individual species is not recommended, since the unusual physical regime of the Great Lakes makes it likely that responses of individual species to their chemical environment in the Great Lakes will vary in fundamental ways from those in other lakes. Therefore, there is an urgent need for the development of an objective, quantifiable index specific to the Great Lakes to permit use of phytoplankton data in the assessment of “ecosystem health”.

Last Updated
State of the Great Lakes 2003

Phosphorus Concentrations and Loadings
Indicator #111

Overall Assessment

Status: **Open Lake: Mixed Nearshore: Poor**
Trend: **Open Lake: Undetermined Nearshore: Undetermined**
Primary Factors Determining Status and Trend: **Strong efforts begun in the 1970s to reduce phosphorus loadings have been successful in maintaining or reducing nutrient concentrations in the Lakes, although high concentrations still occur locally in some embayments, harbors and nearshore areas.**

Lake-by-Lake Assessment

Lake Superior

Status: Open Lake: Good Nearshore: Undetermined
Trend: Open Lake: Undetermined Nearshore: Undetermined
Primary Factors Determining Status and Trend: Average concentrations in the open waters are at or below expected levels.

Lake Michigan

Status: Open Lake: Good, Nearshore: Poor
Trend: Open: Improving Nearshore: Undetermined
Primary Factors Determining Status and Trend: Average concentrations in the open waters are at or below expected levels. Phosphorus concentrations may exceed guidelines in nearshore waters for at least part of the growing season.

Lake Huron

Status: Open Lake: Good Nearshore: Poor
Trend: Open Lake: Undetermined Nearshore: Undetermined
Primary Factors Determining Status and Trend: Average concentrations in the open waters are at or below expected levels. Most offshore waters meet the desired guideline but some nearshore areas and embayments experience elevated levels which likely contribute to nuisance algae growths such as the attached green algae, Cladophora and toxic cyanophytes such as Microcystis.

Lake Erie

Status: Open Lake: Fair-Poor   Nearshore: Poor
Trend: Open Lake: Undetermined Nearshore: Undetermined
Primary Factors Determining Status and Trend: Concentrations in the three basins of Lake Erie fluctuate from year to year and frequently exceed target concentrations.   Extensive lawns of Cladophora are common place over the nearshore lakebed in parts of Eastern Lake Erie and are suggestive of phosphorus levels supportive of nuisance levels of algal growth (Higgins *et al*. 2006 and Wilson *et al*. 2005). Phosphorus levels in the nearshore (Canadian shores) of eastern Lake Erie are periodically elevated above basin guideline value of 10 µg/L, however, the highly dynamic nature of water quality in the nearshore has made it difficult to achieve either integrated nearshore assessments of

phosphorus levels, or to relate phosphorus levels to growth of Cladophora.

Lake Ontario

Status:	Open Lake: Good Nearshore: Poor
Trend:	Open Lake: Improving Nearshore: Undetermined
Primary Factors Determining Status and Trend	Average concentrations in the open lake are at or below expected levels. Most offshore waters meet the desired guideline but some nearshore areas and embayments experience elevated levels which likely contribute to nuisance algae growths such as the attached green algae, Cladophora and toxic cyanophytes such as Microcystis. For example, in the Bay of Quinte, control strategies at municipal sewage plants have reduced loadings by two orders of magnitude since the early 1970s. In spite of these controls, mean concentrations measured between May and October in the productive upper bay have remained at 30-35 µg/L in recent years. This level of total phosphorus is indicative of a eutrophic environment. Extensive lawns of Cladophora are common place over the nearshore lakebed in parts of Lake Ontario and are suggestive of phosphorus levels supportive of nuisance levels of algal growth (Higgins *et al*. 2006 and Wilson *et al*. 2005). Phosphorus levels in the nearshore (Canadian shores) are periodically elevated above basin guideline value of 10 µg/L, however, the highly dynamic nature of water quality in the nearshore has made it difficult to achieve either integrated nearshore assessments of phosphorus levels, or to relate phosphorus levels to growth of Cladophora.

Purpose

This indicator assesses total phosphorus levels in the Great Lakes, and is used to support the evaluation of trophic status and food web dynamics in the Great Lakes. Phosphorus is an essential element for all organisms and is often the limiting factor for aquatic plant growth in the Great Lakes. Although phosphorus occurs naturally, the historical problems caused by elevated levels have originated from anthropogenic sources. Detergents, sewage treatment plant effluent, agricultural and industrial sources have historically introduced large amounts into the Lakes.

Ecosystem Objective

The goals of phosphorus control are to maintain an oligotrophic state in Lakes Superior, Huron and Michigan; to maintain algal biomass below that of a nuisance condition in Lakes Erie and Ontario; and to eliminate algal nuisance growth in bays and in other areas wherever they occur (GLWQA Annex 3). Maximum annual phosphorus loadings to the Great Lakes that would allow achievement of these objectives are listed in the GLWQA. The expected concentrations of total phosphorus in the open waters of the Great Lakes, if the maximum annual loads are maintained, are listed in the following table: (insert Table 1: Phosphorus guidelines for the Great Lakes)

State of the Ecosystem

Strong efforts begun in the 1970s to reduce phosphorus loadings have been successful in maintaining or reducing nutrient concentrations in the Lakes, although high concentrations still occur locally in some embayments, harbors and nearshore areas. Phosphorus loads have decreased in part due to changes in agricultural practices (e.g., conservation tillage and integrated crop management), promotion of phosphorus-free detergents, and improvements made to sewage treatment plants and sewer systems.

Average concentrations in the open waters of Lakes Superior, Michigan, Huron, and Ontario are at or below expected levels. Concentrations in the three basins of Lake Erie fluctuate from year to year (Figure 1) and frequently exceed target concentrations. In Lakes Ontario and Huron, most offshore waters meet the desired guideline but some nearshore areas and embayments experience elevated levels which likely contribute to nuisance algae growths such as the attached green algae, Cladophora and toxic cyanophytes such as Microcystis. For example, in the Bay of Quinte, Lake Ontario, control strategies at municipal sewage plants have reduced loadings by two orders of magnitude since the early 1970's. In spite of these controls, mean concentrations measured between May and October in the productive upper bay have remained at 30-35 µg/L in recent years. This level of total phosphorus is indicative of a eutrophic environment. Typical of other zebra mussel-infested and phosphorus enriched bays in the Great Lakes, toxic cyanophytes such as Microcystis have increased in abundance in recent years with blooms occurring in late August and early September.

Similarly, phosphorus concentrations may exceed phosphorus guidelines in nearshore waters for at least part of the growing season. Lake Michigan's eastern shoreline, when sampled in June, 2004, had a median concentration of 9 µg/L. Summer sampling at the same locations yielded a median concentration of 6 µg/L, with a number of sampling locations at or above the 7 µg/L guideline. By comparison, open water concentrations during spring 2004 was 3.7 µg/L. Cladophora growth is a problem on much of this shoreline. In parts of Eastern Lake Erie and Lake Ontario extensive lawns of Cladophora are common place and are suggestive of phosphorus levels supportive of nuisance levels of algal growth (Higgins *et al*. 2006 and Wilson *et al*. 2005). Phosphorus levels in the nearshore (Canadian shores) of eastern Lake Erie and Lake Ontario and are periodically elevated above basin guideline value of 10 µg/L, however, the highly dynamic nature of water quality in the nearshore has made it difficult to achieve either integrated nearshore assessments of phosphorus levels, or to relate phosphorus levels to growth of Cladophora. Phosphorus concentration in nearshore areas tend to be highly variable over time and from point to point, at times on the scale of meters, due to influences of tributary and other shore-based discharges, weather, biological activity and lake circulation.

Pressures

Even if current phosphorus controls are maintained, additional loadings can be expected. Increasing numbers of people living along the Lakes will exert increasing demands on existing sewage treatment facilities. Even if current phosphorus concentration discharge limits are maintained, increased populations may result in increased loads. Phosphorus management plans with target loads need to be established for major municipalities. Recent research indicates that even weather and climate changes may be influencing the phosphorus loads to the lakes through changes in snowmelt and storm patterns.

Management Implications

Because of its key role as the limiting nutrient for productivity and food web dynamics of the Great Lakes, vigilance must be exercised by water management agencies with respect to phosphorus loads to prevent a return to conditions observed in the 1960s. Future activities that are likely to be needed include: 1) Assess the capacity and operation of existing sewage treatment plants in the context of increasing human populations being served. Utilization of state of the art technology to lower effluent concentrations below current targets should be considered for retrofits and upgrades to sewage treatment plants; 2) Conduct studies of the urban and rural nonpoint contributions of phosphorus to better our understanding of their current overall importance, especially with regards to nearshore eutrophication and Cladophora abundance, and 3) Conduct sufficient tributary and point source monitoring to track Phosphorus loadings and to better understand the relative importance of various sources.

The surveillance of phosphorus concentrations in the Great Lakes is ongoing and the data are considered to be reliable. Plans are being formulated for an interagency laboratory comparison of total phosphorus analysis. Enhanced monitoring of nearshore and embayment sites as well as tributary monitoring may be accomplished with better coordination with existing state and provincial environmental programs. Especially if they are tied to a framework, such as a Lakewide Management Plan (LaMP) that recognizes the unique phosphorus related sensitivities of the nearshore and also provides the means to interrelate nearshore and offshore nutrient conditions and concerns. The recent reappearance of Cladophora in some areas of the Great Lakes strengthens the importance of nearshore measurements.

The data needed to support loadings calculations have not been collected since 1991 in all lakes except Lake Erie, which has loadings information up to 2002, and Lake Michigan with information for 1994 and 1995. Efforts to do so should be reinstated for at least Lake Erie, and work is underway to accomplish this. For the other lakes, the loadings component of this SOLEC indicator will remain unreported, and changes in the different sources of phosphorus to these Lakes may go undetected.

Acknowledgments
Authors: Alice Dove, Environment Canada, Burlington, ON & Glenn Warren, US EPA Chicago, Ill
Additional contributions from: Scott Millard, Environment Canada, Burlington, ON & Todd Howell, Ontario Ministry of Environment, Toronto, ON

Data Sources

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Richardson, V. Environmental Conservation Branch, Environment Canada.

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SOLEC 2006

Lake	Phosphorus Guideline (µg/L)
Superior	5
Huron	5
Michigan	7
Erie - Western Basin	15
Erie - Central Basin	10
Erie - Eastern Basin	10
Ontario	10

Table 1. Phosphorus guidelines for the Great Lakes (GLWQA 1978)

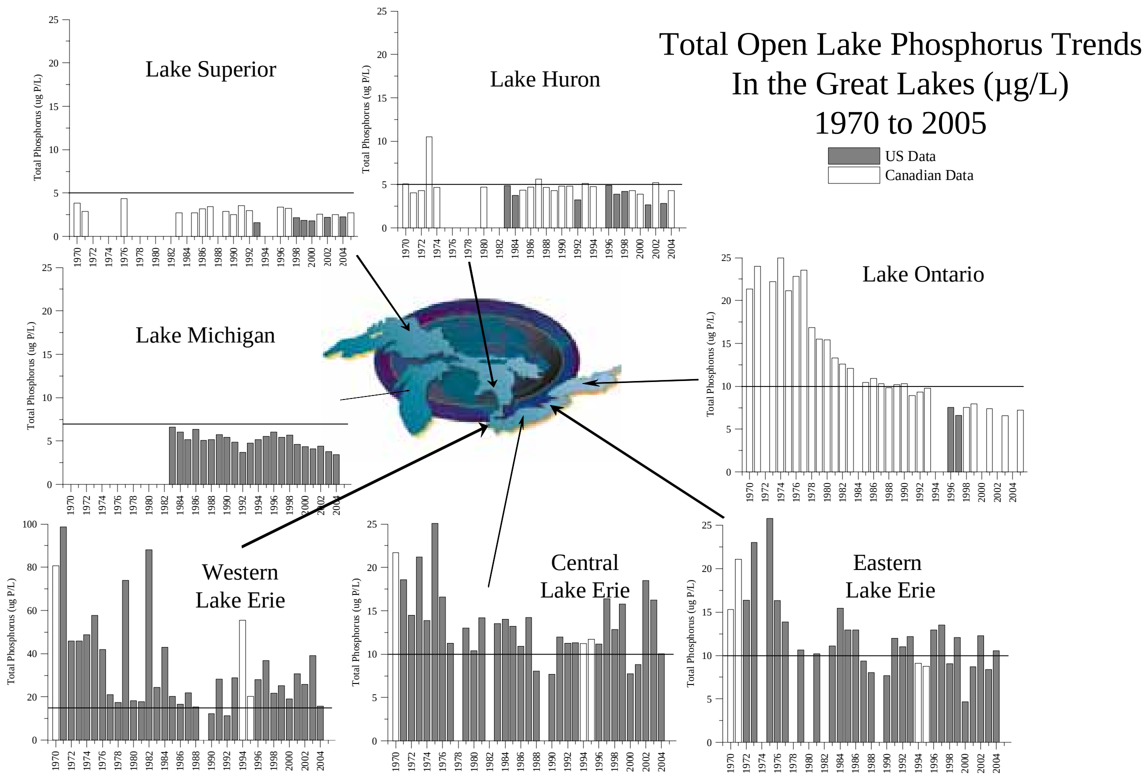

Figure 1. Total Phosphorus Trends in the Great Lakes 1970 to 2005. Blanks indicate no sampling. Horizontal line on each graph represents the phosphorus guideline as listed in the Great Lakes Water Quality Agreement for each Lake. Environment Canada data (white bars - average of spring, surface measurements at open lake sites) are used for Lakes Ontario, Huron and Superior, and are supplemented by US data for years in which no monitoring was conducted on that lake. U.S. Environmental Protection Agency data (black bars - average of spring measurements, all depths at open lake sites) are used for the three basins of Lake Erie and for Lake Michigan, and are supplemented by Canadian data for years in which no US monitoring was conducted on that lake.
Source: Science and Technology Branch, Environment Canada and Great Lakes National Program Office, U.S. Environmental Protection Agency

Contaminants in Young-of-the-Year Spottail Shiners
Indicator #114

Overall Assessment

Status:	**Mixed**
Trend:	**Improving**
Primary Factors Determining Status and Trend	**Although levels of polychlorinated biphenyls (PCBs) in forage fish have decreased below the guideline at many sites around the Great Lakes, PCB levels remain elevated. As well, dichloro-diphenyl-trichloroethane (DDT) levels in forage fish have declined but remain above the guideline at most Great Lakes' locations.**

Lake-by-Lake Assessment

Lake Superior

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB concentrations in Lake Superior forage fish have declined over the period of record and are currently below the guideline at all sample sites. DDT has declined to levels near the guideline, except for Nipigon Bay, where the most current levels (1990) are elevated.

Lake Michigan

Status:	N/A
Trend:	N/A
Primary Factors Determining Status and Trend	N/A

Lake Huron

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB levels in Lake Huron forage fish have remained static or declined over the period of record and are currently at or below the guideline. DDT levels, however, remain elevated at Collingwood Harbour.

Lake Erie

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB levels in Lake Erie forage fish have declined to levels at or below the guideline. DDT has also declined over the period of record but remains above the guideline.

Lake Ontario

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB levels in Lake Ontario forage fish have declined significantly over the period of record and the most recent levels are at or below the guideline. At some sites, DDT in forage fish has declined considerably, however, levels remain at or above the guideline at all sites. Mirex has also declined and has remained below the detection limit in recent years.

Purpose

•To assess the levels of persistent bioaccumulative toxic (PBT) chemicals in young-of-the-year spottail shiners;
•To infer local areas of elevated contaminant levels and potential harm to fish-eating wildlife; and
•To monitor contaminant trends over time for the nearshore waters of the Great Lakes.

Ecosystem Objective

Concentrations of toxic contaminants in juvenile forage fish should not pose a risk to fish-eating wildlife. The Aquatic Life Guidelines in Annex 1 of the Great Lakes Water Quality Agreement (United States and Canada, 1987), the New York State Department of Environmental Conservation (NYSDEC) Fish Flesh Criteria (Newell *et al*., 1987) for the protection of piscivorous wildlife, and the Canadian Environmental Quality Guidelines (CCME, 2001) are used as acceptable guidelines for this indicator. Canadian Council of Ministers of the Environment Contaminants monitored in forage fish and their respective guidelines are listed in Table 1.

State of the Ecosystem

Contaminant levels in fish are important indicators of contaminant levels in an aquatic ecosystem due to the bioaccumulation of organochlorine chemicals in fish tissue. Contaminants that are often undetectable in water may be detected in juvenile fish. Juvenile spottail shiner (*Notropis hudsonius*) was originally selected by Suns and Rees (1978) as the principal biomonitor for assessing trends in contaminant levels in local or nearshore areas. It was chosen as the preferred species because of its limited range in the first year of life; undifferentiated feeding habits in early stages; importance as a forage fish; and its presence throughout the Great Lakes. The position it holds in the food chain also creates an important link for contaminant transfer to higher trophic levels. However, at some sites along the Great Lakes spottail shiners are not as abundant as they once were, and therefore can be difficult to collect. In this updated indicator report, bluntnose minnow (*Pimephales notatus)* have been included in the Lake Huron/Georgian Bay dataset.

With the incorporation of the CCME guidelines, the total DDT tissue residue criterion is exceeded at most locations. After total DDT, PCB is the contaminant most frequently exceeding the guideline. Mirex was historically detected and exceeded the guideline at Lake Ontario locations. However, mirex concentrations over the past 10 years have been below detection. Other contaminants listed in Table 1 are often not detected, or are present at levels well below the guidelines.

Lake Erie

Trends of contaminants in spottail shiners were examined for four locations in Lake Erie: Big Creek, Thunder Bay Beach, Grand River and Leamington (Figure 1). Overall, the trends show higher concentrations of PCBs in the early years (1970s) with a steady decline over time. At Big Creek, PCB concentrations were elevated (>300 ng/g) until 1986. Since 1986, concentrations have remained near the guideline (100 ng/g). At the Grand River and Thunder Bay beach locations, PCB concentrations exceeded the guideline in the late 1970s, but have declined in recent years and are currently below the IJC guideline (100 ng/g). At Leamington, PCB concentrations were considerably higher than at the other Lake Erie sites. Although they declined from 888 ng/g in 1975 to 204 ng/g in 2001, the concentrations exceeded the guideline in all years except for a period in the early to mid-1990s. In the most recent collection (2004), levels have declined to 136 ng/g, which only marginally exceeds the IJC guideline.

Total DDT concentrations at Lake Erie sites have also been declining. Concentrations of total DDT at Big Creek, Grand River and Thunder Bay Beach have declined considerably to levels close to the guideline (14 ng/g). Maximum concentrations at these sites were found in the 1970s and ranged from 38 ng/g at Thunder Bay Beach to 75 ng/g at Big Creek. At Leamington, however, total DDT levels peaked at 183 ng/g in 1986. Since then, levels have declined, but they remain above the guideline.

Lake Huron

Trend data are available for two Lake Huron sites: Collingwood Harbour and Nottawasaga River (Figure 2). At Collingwood Harbour the highest PCB concentrations were found when sampling began in 1987 (206 ng/g). Since then, PCB concentrations have remained near or just below the guideline. At the Nottawasaga River the highest concentration of PCBs was observed in 1977 (90 ng/g). Concentrations declined to less than the detection limit by 1987 and in 2002 were detected at very low levels.

Total DDT concentrations at Collingwood Harbour have remained near 40 ng/g since 1987. The guideline of 14 ng/g was exceeded in all years. At the Nottawasaga River site, there has been a steady decline in total DDT since 1977 when concentrations peaked at 106 ng/g. In 2002, levels were below the guideline.

Lake Superior

Trend data were examined for four locations in Lake Superior: Mission River, Nipigon Bay, Jackfish Bay and Kam River (Figure 3). Recent data are not available for the first three locations.

Generally PCB concentrations were low in all years and at all locations. The highest PCB concentrations in Lake Superior were found at the Mission River in 1983 (139 ng/g). All other analytical results were below the guideline (100 ng/g). The highest concentrations of PCBs at the other three Lake Superior sites also occurred in 1983 and ranged from 51 ng/g at Nipigon Bay to 89 ng/g at Jackfish Bay.

At Mission River and Nipigon Bay, total DDT levels were high in the late 1970s but decreased below the guideline (14 ng/g) by the mid-1980s. In 1990, the DDT level at Nipigon Bay was 66 ng/g, which is the highest concentration observed in juvenile fish from any Lake Superior site to date. At Jackfish Bay and the Kam River, total DDT levels were below the guideline each year, except for the Kam River in 1991 when levels rose to 37 ng/g.

Lake Ontario
Contaminant concentrations from five sites were examined for trends: Twelve Mile Creek, Burlington Beach, Bronte Creek, Credit River and the Humber River (Figure 4). PCBs, total DDT and mirex were generally higher at these (and other Lake Ontario) locations than elsewhere in the Great Lakes. Overall, PCBs at all locations tended to be higher in the early years, ranging from 3 to 30 times the guideline. The highest concentrations of PCBs were found at the Humber River in 1978 (2938 ng/g). In recent years PCBs at the five sites generally have ranged from 100 ng/g to 200 ng/g.

Total DDT concentrations at all five locations have declined considerably since the late 1970s and early 1980s. However, at all of these locations, levels in juvenile fish still exceed the guideline (14 ng/g). The maximum reported concentration was at the Humber River in 1978 (443 ng/g). Currently, the typical concentration of total DDT at all five locations is approximately 50 ng/g. Mirex has been detected intermittently at all five locations. The maximum concentration was 37 ng/g at the Credit River in 1987. Since 1993, mirex has been below the detection limit at all of these locations.

Lake Michigan
No spottail shiners were sampled from Lake Michigan.

Pressures
New and emerging contaminants, such as polybrominated diphenyl ethers, may apply new pressures on Great Lakes' water quality. Analytical methods need to be developed and tissue residue guidelines need to be established for these contaminants. Monitoring programs should also be initiated.

Management Implications
For those contaminants that exceed the wildlife protection guidelines, additional remediation efforts may be required. Continued monitoring is essential to determine the status of contaminants in forage fish from the Great Lakes.

Comments from the author(s)
Organochlorine contaminants have declined in juvenile fish throughout the Great Lakes. However, regular monitoring should continue for all of these areas to determine if levels are below wildlife protection guidelines. Analytical methods should be improved to accommodate revised guidelines and to include additional contaminants such as dioxins and furans, dioxin-like PCBs and PBDEs. For Lake Superior, the historical data do not include toxaphene concentrations. Since this contaminant is responsible for some consumption restrictions on sport fish from this lake (MOE, 2005), it is recommended that analysis of this contaminant be included in any future biomonitoring studies in Lake Superior.

Spottail shiners have been a useful indicator of contaminant levels in the past. However, this species is less abundant than it has been. Due to the difficulties in collecting this species in all areas of the Great Lakes, consideration should be given to adopting other forage fish species as indicators when spottail shiners are not available. This year, bluntnose minnows were used for one site in Georgian Bay. This will improve temporal and spatial trend data and result in a more complete dataset for the Great Lakes.

Acknowledgments
Authors: Emily Awad, Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment, Etobicoke, ON; and
Alan Hayton, Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment, Etobicoke, ON.
Data: Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment.

Data Sources

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Source: Ontario Ministry of the Environment

Figure 2. PCB and total DDT levels in juvenile spottail shiners from two locations in Lake Huron. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.
Source: Ontario Ministry of the Environment

Figure 3. PCB and total DDT levels in juvenile spottail shiners from four locations in Lake Superior. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.
Source: Ontario Ministry of the Environment

Figure 4. PCB, mirex and total DDT levels in juvenile spottail shiners from five locations in Lake Ontario. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline for PCBs and total DDT. For mirex, the red line indicates the detection limit (5ng/g). When not detected, one half of the detection limit was used to calculate the mean concentration.
Source: Ontario Ministry of the Environment

Last updated
SOLEC 2006

Contaminant	Tissue Residue Criteria (ng/g)
PCBs	100*
DDT, DDD, DDE	14[†] (formerly 200)
Chlordane	500
Dioxin/Furans	0.00071[a] (formerly 0.003)
Hexachlorobenzene	330
Hexachlorocyclohexane (BHC)	100
Mirex	below detection*
Octachlorostyrene	20

*IJC Aquatic Life Guideline for PCBs (IJC 1988); [a] Environment Canada, 2000 (CCME 2001); [†] Environment Canada, 1997 (CCME 2001). All other values from NYSDEC Fish Flesh Criteria (Newell *et al*. 1987). Guidelines based on mammals and birds.

Table 1. Tissue Residue Criteria for various organochlorine chemicals or chemical groups for the protection of wildlife consumers of aquatic biota.

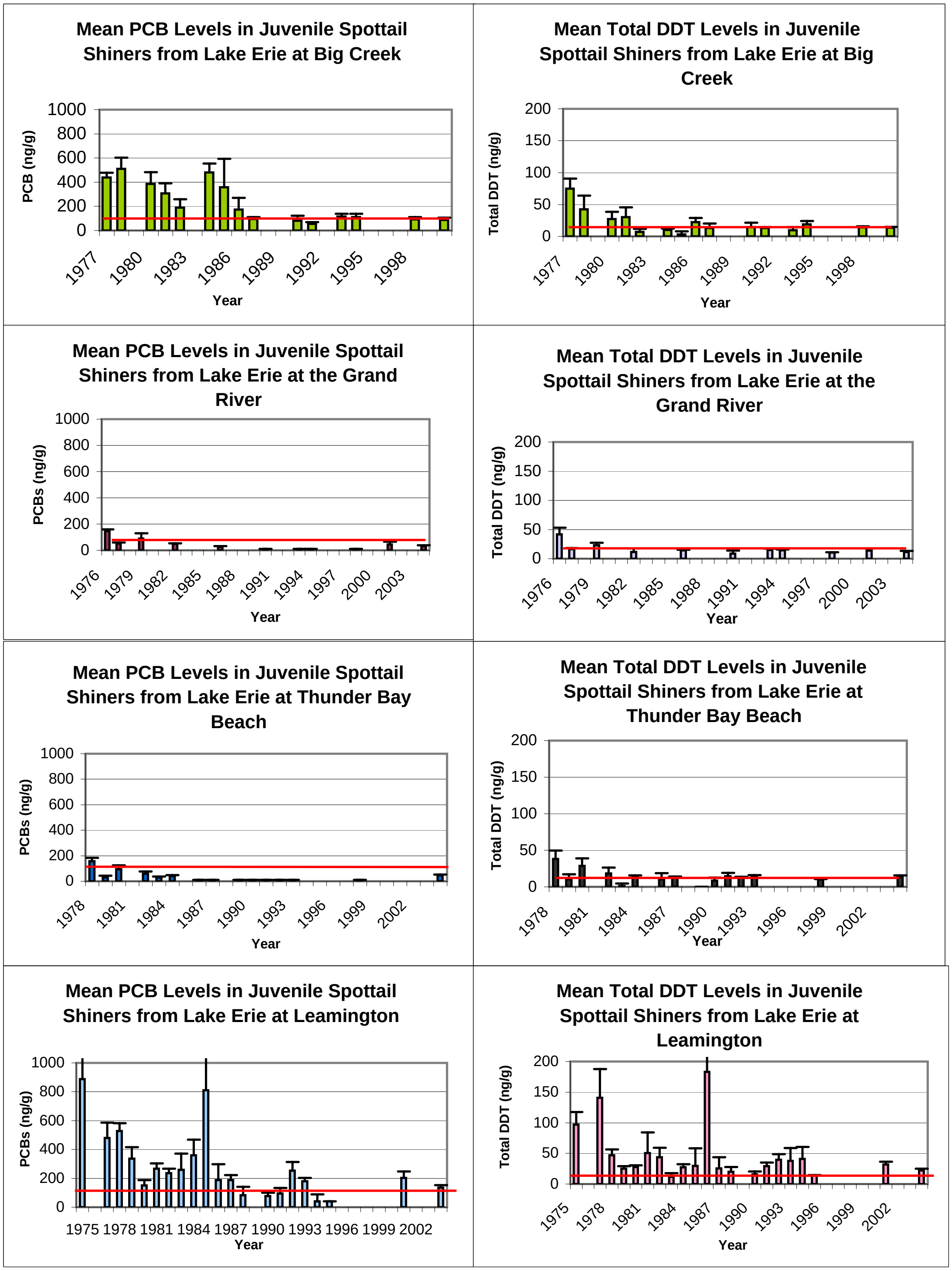
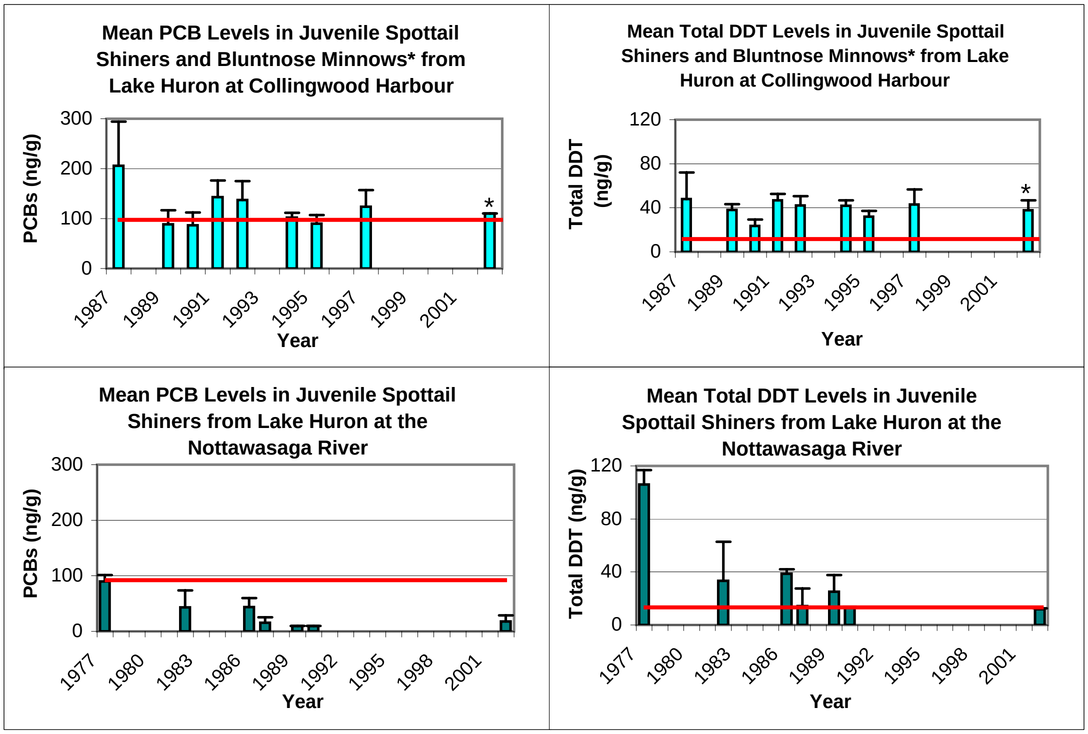


Figure 1. PCB and total DDT levels in juvenille spottail shiners from four locations in Lake Erie. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.

Source: Ontario Ministry of the Environment



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Source: Ontario Ministry of the Environment

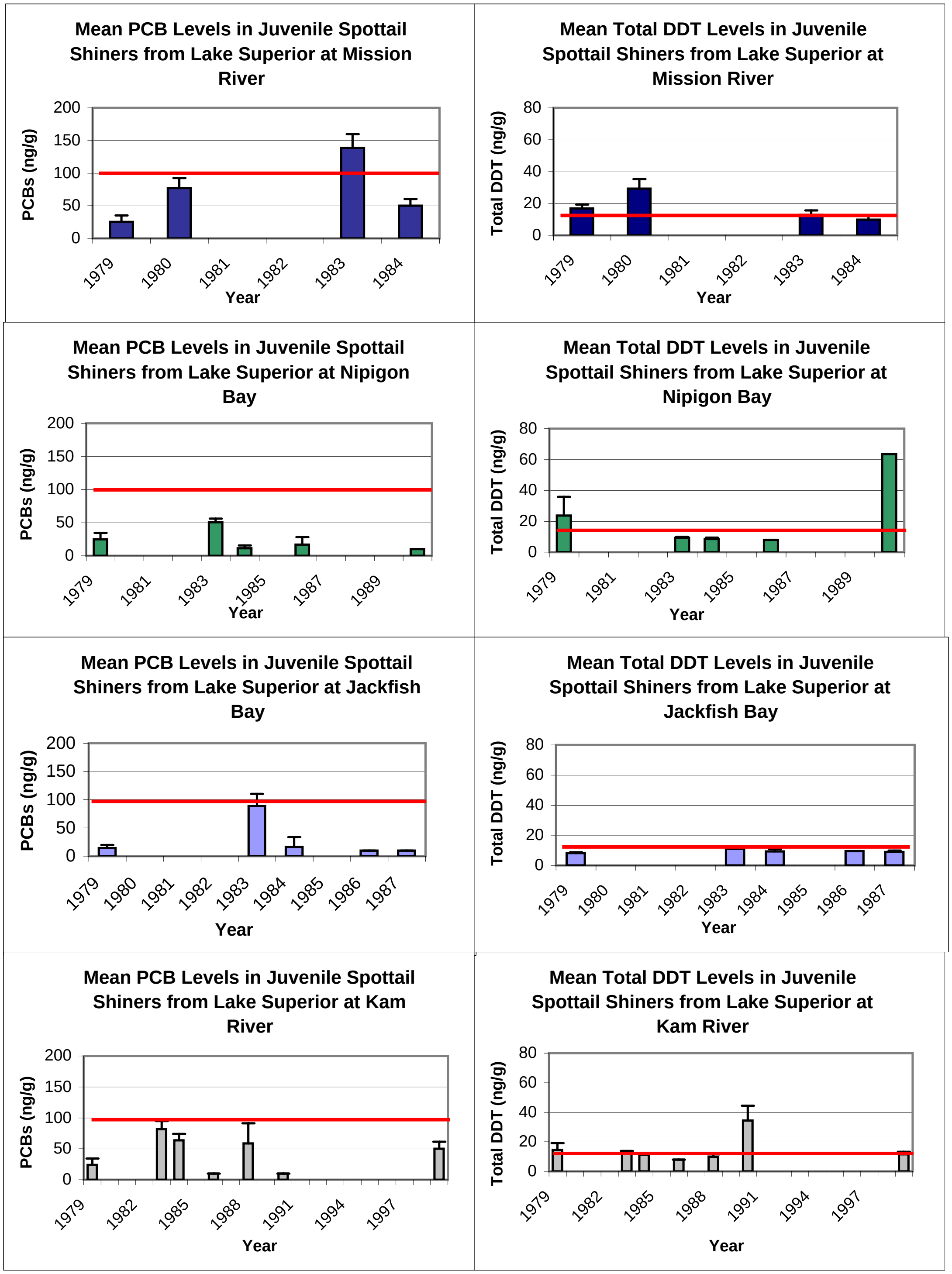
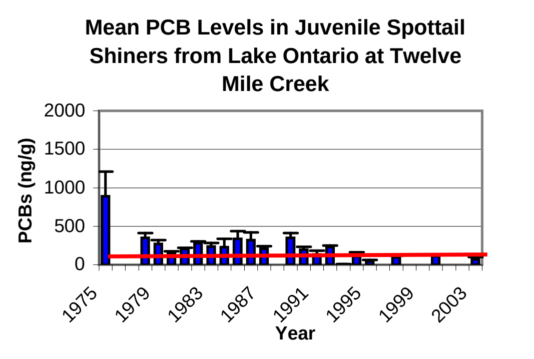
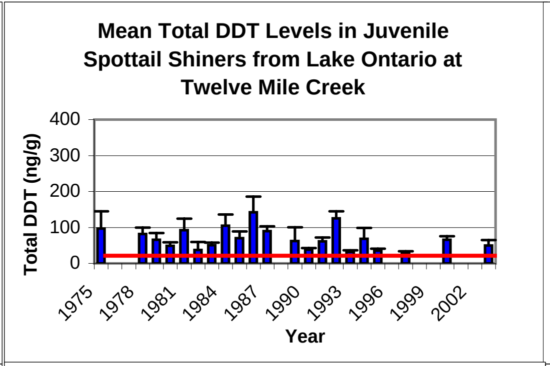
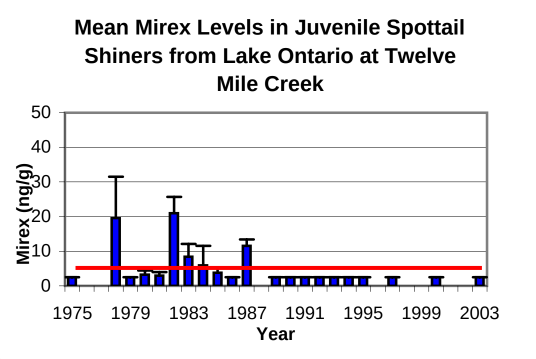


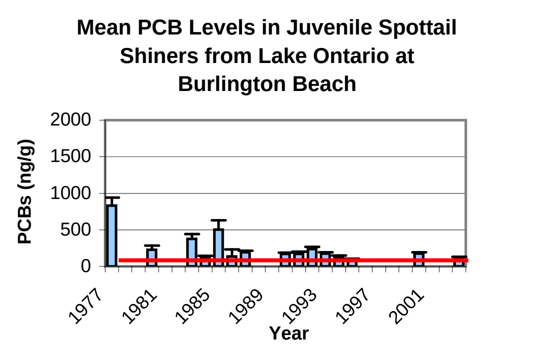
Figure 3. PCB and total DDT levels in juvenille spottail shiners from four locations in Lake Superior. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.

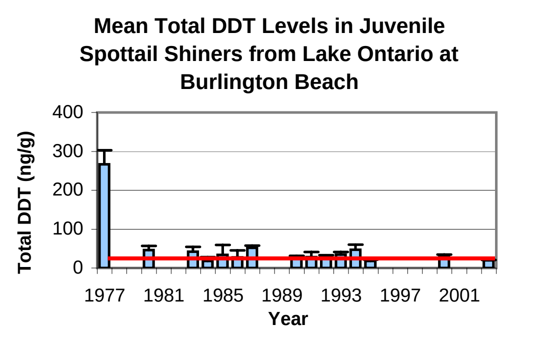
Source: Ontario Ministry of the Environment

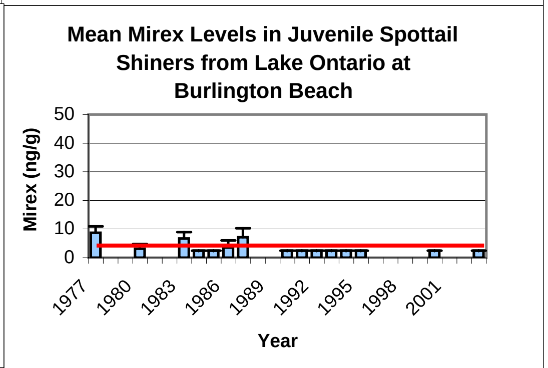

Mean PCB Levels in Juvenile Spottail Shiners from Lake Ontario at Twelve Mile Creek
PCBs (ng/g)
2000
1500
1000
500
0
1975
1979
1983
1987
1991
1995
1999
2003
Year

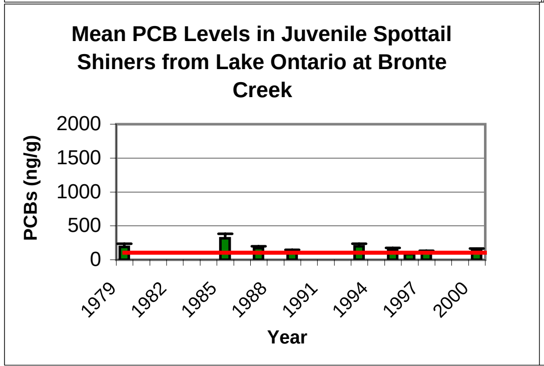

Mean Total DDT Levels in Juvenile Spottail Shiners from Lake Ontario at Twelve Mile Creek
Total DDT (ng/g)
400
300
200
100
0
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
Year

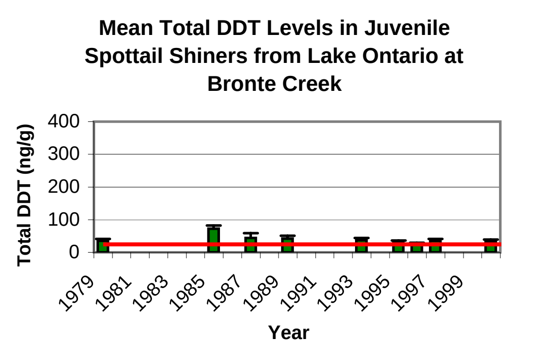

Mean Mirex Levels in Juvenile Spottail Shiners from Lake Ontario at Twelve Mile Creek
Mirex (ng/g)
50
40
30
20
10
0
1975
1979
1983
1987
1991
1995
1999
2003
Year


Mean PCB Levels in Juvenile Spottail Shiners from Lake Ontario at Burlington Beach
PCBs (ng/g)
2000
1500
1000
500
0
1977
1981
1985
1989
1993
1997
2001
Year


Mean Total DDT Levels in Juvenile Spottail Shiners from Lake Ontario at Burlington Beach
Total DDT (ng/g)
400
300
200
100
0
1977
1981
1985
1989
1993
1997
2001
Year


Mean Mirex Levels in Juvenile Spottail Shiners from Lake Ontario at Burlington Beach
Mirex (ng/g)
50
40
30
20
10
0
1977
1980
1983
1986
1989
1992
1995
1998
2001
Year


Mean PCB Levels in Juvenile Spottail Shiners from Lake Ontario at Bronte Creek
PCBs (ng/g)
2000
1500
1000
500
0
1979
1982
1985
1988
1991
1994
1997
2000
Year


Mean Total DDT Levels in Juvenile Spottail Shiners from Lake Ontario at Bronte Creek
Total DDT (ng/g)
400
300
200
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1979
1981
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1997
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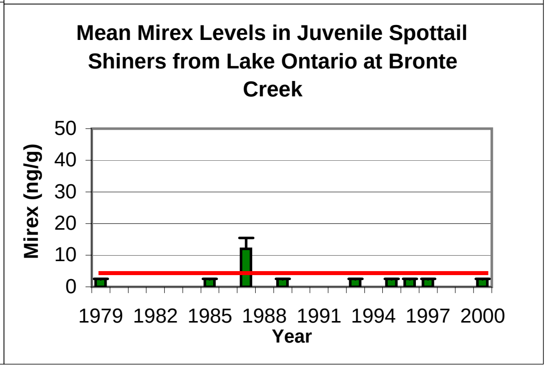
Year


Mean Mirex Levels in Juvenile Spottail Shiners from Lake Ontario at Bronte Creek
Mirex (ng/g)
50
40
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20
10
0
1979
1982
1985
1988
1991
1994
1997
2000
Year

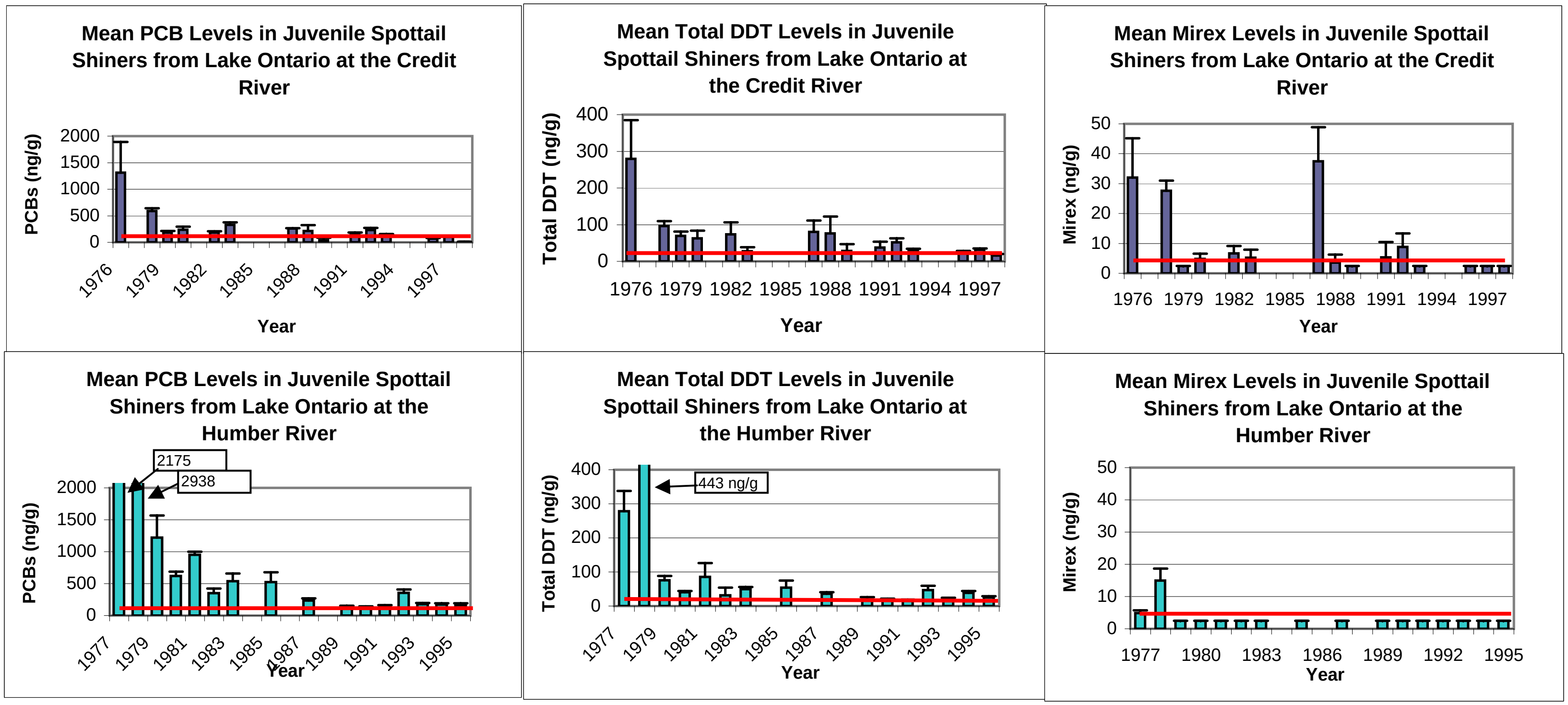

Figure 4. PCB, mirex and total DDT levels in juvenille spottail shiners from five locations in Lake Ontario. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline for PCBs and total DDT. For mirex, the red line indicates the detection limit of 5 ng/g. When not detected, one half of the detection limit was used to calculate the mean concentration.

Source: Ontario Ministry of the Environment

Contaminants in Colonial Nesting Waterbirds
Indicator #115

Overall Assessment

Status: Mixed
Trend: Improving
Primary Factors Determining Status and Trend: The primary factors being used are: 1. the change in contaminant concentrations in Herring Gull eggs between when they were first measured (usually 1974) and currently, in 2005 (Jermyn-Gee et al. 2005; CWS, unpubl.), 2. the overall ranking of contaminant concentrations at the 15 Great Lakes Herring Gull Egg Monitoring Sites (Weseloh et al. 2006) and 3. the direction and relative slope of the change-point regression line calculated for each compound at each site. (Pekarik and Weseloh 1996; Weseloh et al. 2003, 2005; CWS, unpubl.) Overall, most contaminants have declined substantially (>90%) since first measured. Spatially, some sites in 2-3 of the lakes were much more contaminated than others. Temporally, more than 70% of all contaminant concentrations at all colonies (N=105) were currently declining as fast or faster than they did in the past.

Lake-by-Lake Assessment

Lake Superior

Status: Good
Trend: Improving
Primary Factors Determining Status and Trend: For 6 contaminants that have been measured since the program started in 1974 (PCBs, DDE, HCB, HE, mirex and dieldrin), the two Herring Gull egg monitoring sites in Lake Superior showed declines of 93.9 – 99.8% between then and 2005. Both sites ranked among the lowest for concentrations of 7 major compounds (the above 6 + TCDD) among the 15 monitor sites. The temporal pattern at the two sites showed 71% of colony-contaminant comparisons declining as fast or faster than previously.

Lake Michigan

Status: Mixed
Trend: Improving
Primary Factors Determining Status and Trend: For 6 contaminants that have been measured since the program began, the two Herring Gull egg monitoring sites showed declines of 91.8 – 99.1% between then and 2005. Eggs from one of the Lake Michigan sites ranked as the 3rd most contaminated among the 15 monitor sites; eggs from the other site ranked much lower (9th). The temporal pattern for the two sites showed 86% of the colony-contaminant comparisons declining as fast or faster than previously.

Lake Huron

Status: Mixed
Trend: Improving
Primary Factors Determining: Herring Gull eggs from two of three monitoring sites in Lake Huron were relatively clean. The third site, in Saginaw Bay, had the most contaminated

Status and Trend — gull eggs among all sites tested and reduced the overall status of this indicator in Lake Huron. The three sites showed contaminant declines of 68.9 – 99.7% in gull eggs in 2005. Two of three sites ranked among the lowest for concentrations for 7 major compounds among 15 sites.
The temporal pattern at the three sites showed 86% of colony-contaminant comparisons declining as fast or faster than previously.

Lake Erie

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	Of the two monitor sites in Lake Erie, the most easterly, at Port Colborne, had the cleanest gull eggs of all 15 sites tested. Eggs from Middle Island, in the Western Basin, were considerably more contaminated. The two sites showed contaminant declines of 80.2 – 99.3% in gull eggs in 2005. Eggs from Middle Island were in the mid-range and those from Port Colborne were the lowest for contaminants. The temporal pattern at the two sites showed 93% of colony-contaminant comparisons declining as fast or faster than previously.

Lake Ontario

Status:	Poor
Trend:	Improving
Primary Factors Determining Status and Trend	Eggs from the three Lake Ontario Herring Gull Monitoring Sites showed declines of 88.6 – 99.0% in 2005. The three sites ranked among the top 8 for concentrations of contaminants in gull eggs. Temporally, 76% of colony-contaminant comparisons were declining as fast or faster than previously.

Purpose

•To assess current chemical concentrations and trends in representative colonial waterbirds (gulls, terns, cormorants and/or herons) on the Great Lakes;
•To assess ecological and physiological endpoints in representative colonial waterbirds (gulls, terns, cormorants and/or herons) on the Great Lakes; and
•To infer and measure the impact of contaminants on the health, i.e. the physiology and breeding characteristics, of the waterbird populations.

Ecosystem Objective

One of the objectives of monitoring colonial waterbirds on the Great Lakes is to track progress toward an environmental condition in which there is no difference in contaminant levels and related biological endpoints between birds on and off the Great Lakes. Other objectives include determining temporal and spatial trends in contaminant levels in colonial waterbirds and detecting changes in their population levels on the Great Lakes. This includes monitoring contaminant levels in Herring Gull eggs to ensure that the levels continue to decline and utilizing these data to promote continued reductions of contaminants in the Great Lakes basin.

State of the Ecosystem

Background

This indicator is important because colonial waterbirds are one of the top aquatic food web predators in the Great Lakes ecosystem and they are very visible and well-known to the public. They bioaccumulate contaminants to the greatest concentration of any trophic level organism and they breed on all the Great Lakes. Thus, they are a very cost efficient monitoring system and allow easy inter-lake comparisons. The current Herring Gull Egg Monitoring Program is the longest continuously running annual wildlife contaminants monitoring program in the world (1974-present). It determines concentrations of up to 20 organochlorines, 65 polychlorinated biphenyls (PCB) congeners and 53 polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzo furan (PCDF) congeners, as well as 16 brominated diphenyl ethers BDEs) congeners (Braune et al. 2003).

Status of Contaminants in Colonial Waterbirds

The Herring Gull Egg Monitoring Program has provided researchers and managers with a powerful tool (a 30-year database) to evaluate changes in contaminant concentrations in Great Lakes wildlife (e.g., see Figure 1). The extreme longevity of the egg database makes it possible to calculate temporal trends in contaminant concentrations in wildlife and to look for significant changes within those trends. The database shows that most contaminants in gull eggs have declined 90% or more since the program began in 1974 (Figure 2). In 2005, PCBs, hexachlorobenzene (HCB), dichlorodiphenyl-dichloroethene (DDE), heptachlor epoxide (HE), dieldrin, mirex and 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) levels measured in eggs from the 15 Annual Monitor Colonies (Figure 3) were analysed for temporal trends (N=105 comparisons). Analysis showed that in 83.8% of cases (88/105), the contaminants were decreasing as fast as or faster in recent years than they had in the past. We interpreted that as a positive sign. In 9.5% of cases (10/105), contaminants were decreasing more slowly than they had in the past (calculated from Bishop et al.1992, Pettit et al.1994, Pekarik et al.1998 and Jermyn-Gee et al. 2005, as per Pekarik and Weseloh 1998). This is viewed as a negative sign. PCBs showed the most frequent reduction in their rates of decline. The decline in contaminant concentrations in gull eggs, however, may not be due wholly to a decrease in contaminants in the environment. Changes in food web dynamics may be playing a role in some of these declines, that is, contaminant exposure at some colonies may have lessened because the birds are now feeding on lower trophic level prey.

The sole exception to these declining herring gull egg contaminant concentrations appears to be brominated diphenyl ethers (BDEs). These compounds, which are used as fire retardants in plastics, furniture cushions, etc., increased dramatically in gull eggs during 1981-2000 (Norstrom et al. 2002). Recent data showed a combined 3.9% decline for the 15 monitor sites from 2000 to 2003 but a 25.3% increase from 2000 to 2005 (CWS, unpubl. data).

A comparison of concentrations of six contaminants (PCBs, HCB, DDE, HE, dieldrin and mirex) at the 15 sites in 2003 and 2005 (N=90 comparisons) was made to show the variability in a short-term (two year) assessment. TCDD was last measured in 2003, therefore for this short-term assessment 2001 and 2003 data were used for an additional 15 comparisons. Of the total 105 comparisons, 89 (84.8%) decreased; only 16 (15.2%) increased. TCDD and PCBs were the most frequently increasing contaminants (Canadian Wildlife Service (CWS) unpublished data). This is illustrated for a single contaminant, PCBs, in Figure 4. Annual fluctuations like these, including both short-term increases and decreases, are part of current contaminant patterns (Figures 1 and 4).

In terms of gross ecological effects of contaminants on colonial waterbirds, e.g. eggshell thinning, failed reproductive success and population declines, most species appear to have recovered. Populations of most species have increased over the past 25-30 years, e.g. see Figure 5 (Blokpoel and Tessier 1993-1998; Austen et al. 1996; Scharf and Shugart 1998, Cuthbert et al. 2001,Weseloh et al. 2002; Morris et al. 2003, Havelka and Weseloh In review, Hebert et al. In review, CWS unpubl. data). Although the gross effects appear to have subsided (but see Custer et al. 1999), there are many other subtle, mostly physiological and genetic endpoints that are being measured now that were not measured in earlier years (Fox et al. 1988, Fox 1993, Grasman et al. 1996, Yauk et al. 2000). A recent and ongoing study, the Fish and Wildlife Health Effects and Exposure Study, is assessing whether there are fish and wildlife health effects in Canadian Areas of Concern (AOCs) similar to those reported for the human population (Environment Canada 2003). To date, the following abnormalities have been found in Herring Gulls in one or more Canadian AOCs on the lower Great Lakes: a male-biased sex ratio in hatchlings, elevated levels of embryonic mortality, indications of feminization in more than 10% of adult males, a reduced or suppressed ability to combat stress, an enlarged thyroid with reduced hormone production and a suppressed immune system. Although there is little question that Herring Gulls and colonial waterbirds on the Great Lakes are healthier now than they were 30 years ago, these findings show that they are in a poorer state of health than are birds from clean reference sites in the Maritimes (Environment Canada 2003).

Pressures
Future pressures for this indicator include all sources of contaminants which reach the Great Lakes. These include those sources that are already well-known, e.g., point sources, re-suspension of sediments, and atmospheric inputs, as well as lesser known ones such as underground leaks from landfill sites. There are also other, non-contaminant factors that regulate the stability of populations, e.g. habitat modification (in the Detroit River), food availability (Lake Superior), interspecific competition at breeding colonies (Lake Ontario) and predation (western Lake Erie). Many of these factors pose much more tangible threats to our ability to collect eggs from these colonies in the future.

Management Implications
Data from the Herring Gull Egg Monitoring Program suggest that, for the most part, contaminant levels in wildlife are continuing to decline at a constant rate. However, even at current contaminant levels, more physiological abnormalities in Herring Gulls occur at Great Lakes sites than at cleaner, reference sites away from the Great Lakes basin. Also, with the noted increase in concentrations of polybrominated diphenyl ethers (PBDEs), steps should be taken to identify and reduce sources of this compound to the Great Lakes. In short, although almost all contaminants are decreasing and many biological impacts have lessened, we do not yet know the full health implications of the subtle effects and of newly monitored contaminants.

Future Activities
The annual collection and analysis of herring gull eggs from 15 sites on both sides of the Great Lakes and the assessment of this species' reproductive success is a permanent part of the CWS

Great Lakes surveillance activities. Likewise, so is the regular monitoring of population levels of most of the colonial waterbird species. The plan is to continue these procedures. Research on improving and expanding the Herring Gull Egg Monitoring Program is done on a more opportunistic, less predictable basis. A lake-by-lake intensive study of possible biological impacts to herring gulls is currently underway in the lower lakes. Recently, ecological tracers (stable isotopes and fatty acids) have been generated from archival eggs as part of the program and provide insights into how food webs in the Great Lakes ecosystem are changing. This information broadens the utility of the program from just examining contaminants to providing insights into ecosystem change. Ecological tracer data are also directly relevant to the interpretation of contaminant monitoring data.

Comments from the author(s)
We have learned much about interpreting the Herring Gull egg contaminants data from associated research studies. However, much of this work is conducted on an opportunistic basis, when funds are available. Several research activities should be incorporated into routine monitoring, e.g. tracking of porphyria, vitamin A deficiencies, and evaluation of the avian immune system. Likewise, more research should focus on new areas, e.g. the impact of endocrine disrupting substances, factors regulating chemically induced genetic mutations and ecological tracers.

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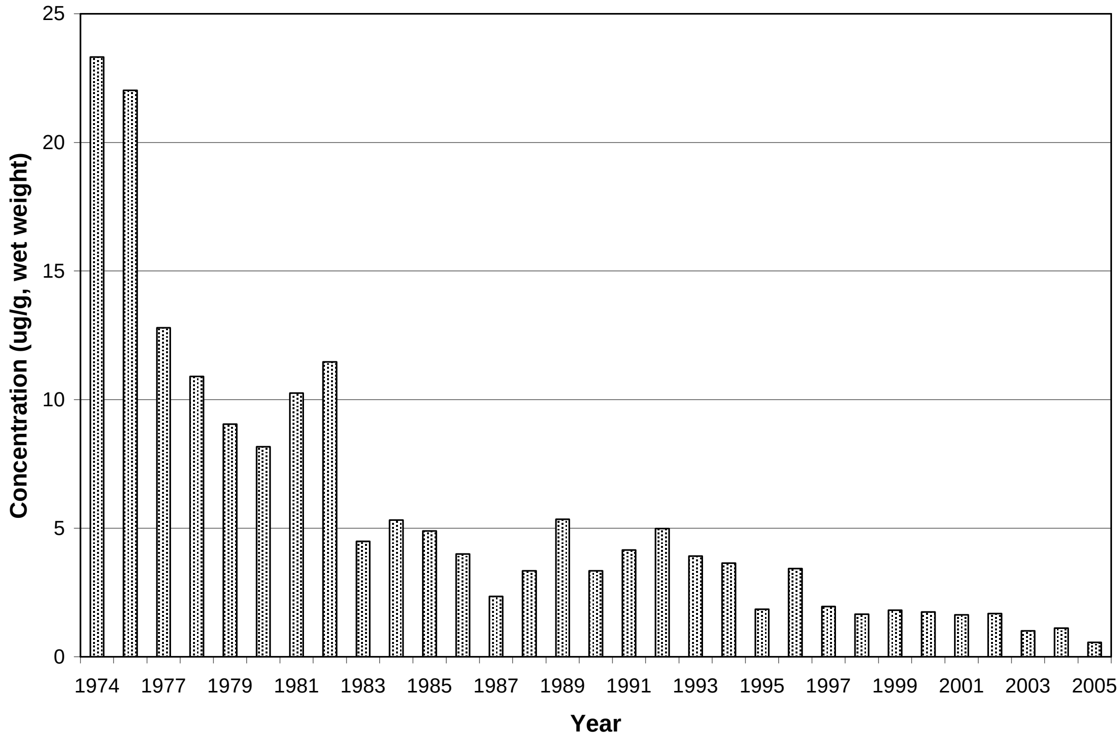
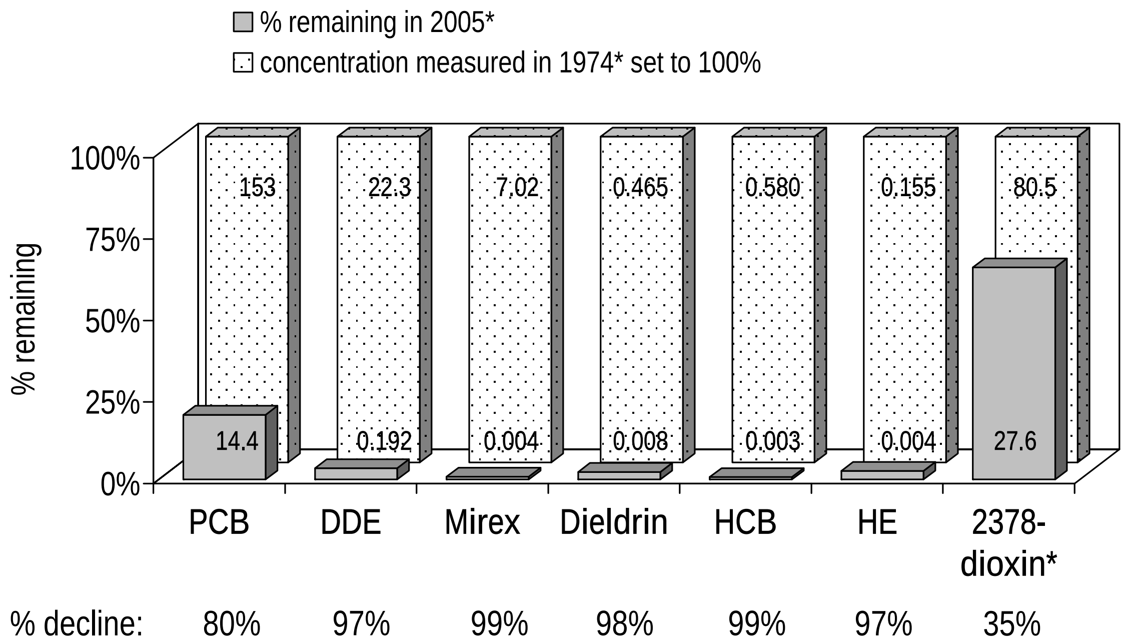


Figure 1. Annual concentration of DDE in Herring Gull eggs, Toronto Harbour, 1974-2005.
Source: Environment Canada, Herring Gull Monitoring Program



* dioxin first measured in 1984 and last measured in 2003

Figure 2. Mean contaminant concentrations and percent decline of 7 contaminants in Herring Gull eggs from year of first analysis to present, Middle Island, Lake Erie. Concentrations in µg/g wet weight except for dioxin in ρg/g wet weight.
Source: Environment Canada, Herring Gull Monitoring Program

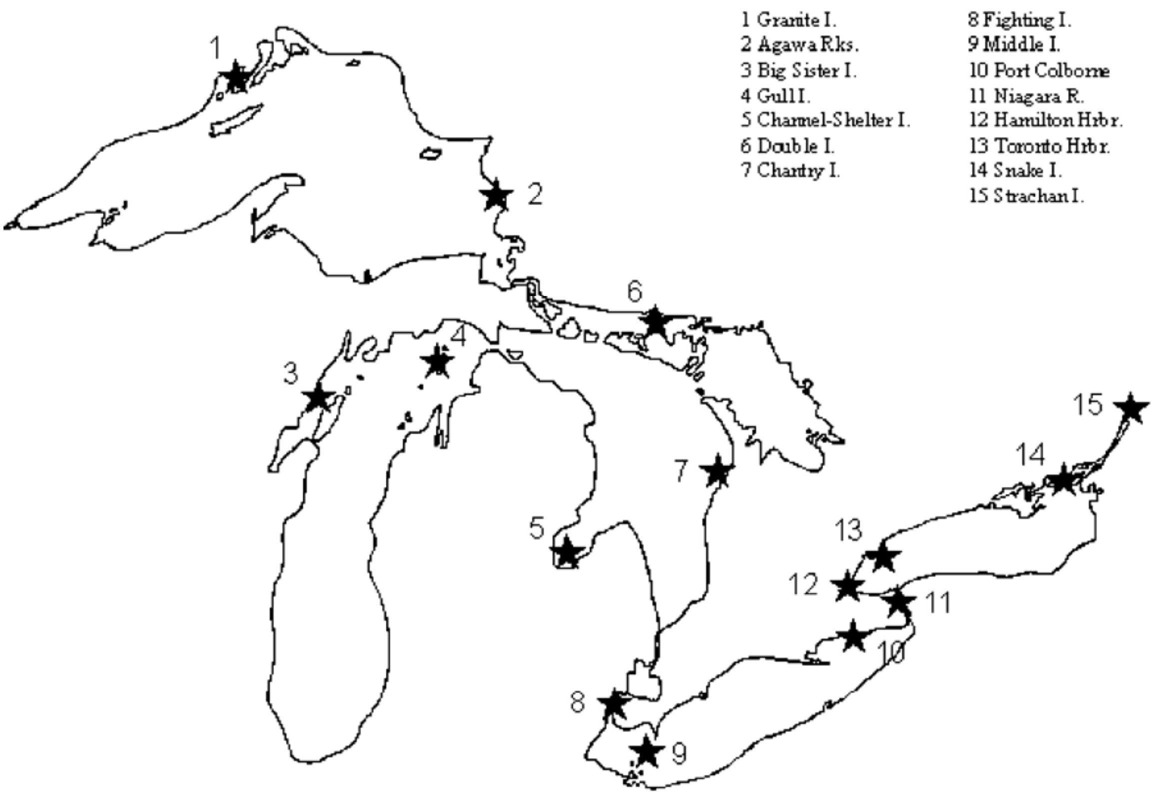


Figure 3. The distribution and locations of the 15 Herring Gull Annual Monitoring Colonies. Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service

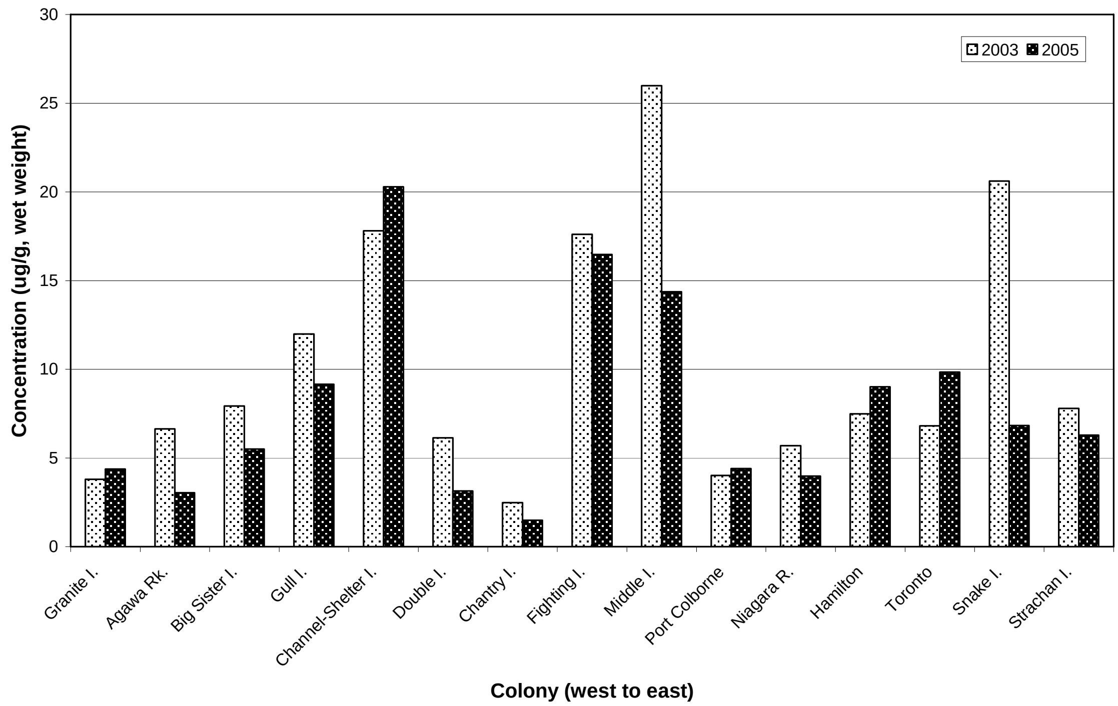


Figure 4. A comparison of PCB concentrations at all sites for 2003 and 2005. Note the between year differences as well as the variation among sites.
Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service

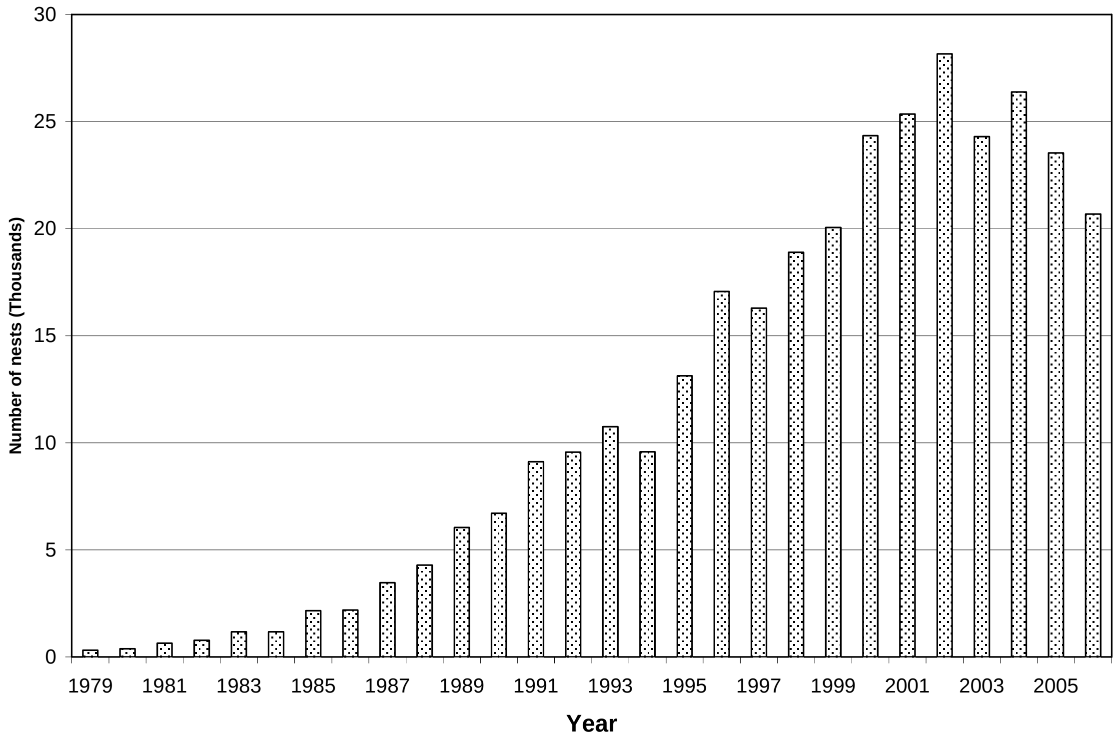


Figure 5. Double-crested Cormorant nests (breeding pairs) on Lake Ontario, 1979-2005.
Source: Environment Canada, Canadian Wildlife Service

Zooplankton Populations
Indicator #116

Overall Assessment

Status: **Mixed**
Trend: **Not Assessed**

Primary Factors Determining Status and Trend: **Changes in community structure are occurring in lakes Michigan, Huron, and Ontario due to declines in cyclopoid copepods and cladocerans. Summer mean size has increased in these lakes concurrent with the increase in the percent of calanoid copepods**

Lake-by-Lake Assessment

Lake Superior

Status: Good
Trend: Unchanging
Primary Factors Determining Status and Trend: Stable summer zooplankton community dominated by large calanoid copepods.

Lake Michigan

Status: Not Assessed
Trend: Undetermined (changing)
Primary Factors Determining Status and Trend: Total summer biomass has been declining since 2004 due to fewer *Daphnia* and cyclopoid copepods. Summer mean size of zooplankton is increasing.

Lake Huron

Status: Not Assessed
Trend: Undetermined (changing)
Primary Factors Determining Status and Trend: Total summer biomass has declined dramatically since 2003 due to fewer *Daphnia*, bosminids, and cyclopoid copepods. Summer mean size of zooplankton is increasing.

Lake Erie

Status: Not Assessed
Trend: Undetermined
Primary Factors Determining Status and Trend: Variable biomass and composition of summer crustacean zooplankton community in each basin. Most diverse zooplankton community in Great Lakes. Very low biomass in Western Basin in August, 2001.

Lake Ontario

Status: Not Assessed
Trend: Undetermined (changing)
Primary Factors Determining Status and Trend: Lowest percentage of calanoid copepods of all Great Lakes. Total summer biomass has declined since 2004 due to a decline in cyclopoid copepods. Summer mean size of zooplankton is increasing.

Purpose
•To directly measure changes in community composition, mean individual size and biomass of zooplankton populations in the Great Lakes basin;
•To indirectly measure zooplankton production; and
•To infer changes in food-web dynamics due to changes in vertebrate or invertebrate predation, system productivity, the type and intensity of predation, and the energy transfer within a system.

Ecosystem Objective
Ultimately, analysis of this indicator should provide information on the biological integrity of the Great Lakes, and lead to the support of a healthy and diverse fishery. Suggested metrics include zooplankton mean length, the ratio of calanoid copepod abundance to that of cyclopoid copepods plus cladocerans and zooplankton biomass. However, the relationship between these objectives and the suggested metrics have not been fully worked out, and no specific criteria have yet been identified for these metrics.

Planktivorous fish often feed size selectively, removing larger cladocerans and copepods. High densities of planktivores result in a reduction of the mean size of zooplankton in a community. A mean individual size of 0.8 mm has been suggested as "optimal" for zooplankton communities sampled with a 153 µm mesh net, indicating a balance between planktivorous and piscivorous fish. Declines in mean size of crustacean zooplankton between spring and late summer may indicate increased predation by young fish or the presence of a greater proportion of immature zooplankton. Interpretation of deviations from this average size objective, and the universality of this objective remain unclear at this time. In particular, questions regarding its applicability to systems impacted by predaceous cladocereans and dreissenids as well as planktivorous fish have been raised.

Gannon and Stemberger (1978) found that cladocerans and cyclopoid copepods are more abundant in nutrient enriched waters of the Great Lakes, while calanoid copepods dominate oligotrophic communities. They reported that areas of the Great Lakes where the density of calanoid copepods comprises over 50% of the summer crustacean zooplankton community (or the ratio of calanoids/cyclopoids + cladocerans >1) could be classified as oligotrophic. As with individual mean size, though, clear objectives have not presently been defined.

State of the Ecosystem
Summer biomass of crustacean zooplankton communities in the offshore waters of Lake Superior has remained at a relatively low but stable level for the past seven years (Figure 1). The plankton community is dominated by large calanoid copepods (*Leptodiaptomus sicilis* and *Limnocalanus macrurus*) that are characteristic of oligotrophic, cold water ecosystems. Biomass is generally higher in the nutrient enriched lower lakes with more annual variation produced by seasonal increases in cladocerans, primarily daphnids and bosminids. Since 2003 the biomass of cladocerans and cyclopoid copepods in Lake Huron has declined dramatically. Data from 2005 suggests that a similar decline may now be occurring in Lake Michigan. Cyclopoid abundance has also begun to decline in Lake Ontario. Mechanisms for these declines are not known at this

time, but may be related to changes in nutrient levels, phytoplankton composition, exotic species interactions, or fish predation pressure.

The proportion of calanoid copepods in Lake Superior has remained fairly stable at 70% (Figure 2) indicating oligotrophic conditions. Summer zooplankton communities in Lakes Michigan and Huron have shown an increasing proportion of calanoid copepods in recent years, suggesting an improved trophic state. Lake Ontario has the lowest proportion of calanoids, followed closely by the nutrient enriched western basin of Lake Erie. Values for the central and eastern basins of Lake Erie are at intermediate levels and exhibit considerable annual variation.

Historical comparisons of this metric are difficult to make because most historical data on zooplankton populations in the Great Lakes seem to have been generated using shallow (20 m) tows. Calanoid copepods tend to be deep living organisms; therefore the use of data generated from shallow tows would tend to contribute a strong bias to this metric. This problem is largely avoided in Lake Erie, particularly in the western and central basins, where most sites are shallower than 20 m. Comparisons in those two basins have shown a statistically significant increase in the ratio of calanoids to cladocerans and cyclopoids between 1970 and 1983-1987, with this increase sustained throughout the 1990s. A similar increase was seen in the eastern basin, although some of the data used to calculate the ratio were generated from shallow tows and are therefore subject to doubt.

Mean length of crustacean zooplankton in the offshore waters of the Great Lakes is generally greater in the spring than during the summer (Figure 3). In the spring, mean zooplankton size in all of the Great Lakes is near the suggested level of 0.8 mm. Mean length in Lake Superior declines during the summer due to the production of immature copepodids, but is still above the criterion. Summer mean length in Lakes Huron and Michigan remain high and have begun to show an increase in recent years. In Lakes Erie and Ontario, the mean length of zooplankton declines considerably in the summer. Whether this decline is due to predation pressure or to the increased abundance of bosminids (0.4 mm mean length) and immature cyclopoids (0.65 mm mean length) is unknown.

Historical data from the eastern basin of Lake Erie, from 1985 to 1998, indicate a fair amount of interannual variability in zooplankton mean length, with values from offshore sites ranging from about 0.5 mm to 0.85 mm (Figure 4). As noted above, interpretation of these data are currently problematic.

Pressures

The zooplankton community might be expected to respond to changes in nutrient and phytoplankton concentrations in the lakes, although the potential magnitude of such "bottom up" effects is not well understood. The most immediate potential threat to the zooplankton communities of the Great Lakes is posed by invasive species. The continued proliferation of dreissenid populations can be expected to impact zooplankton communities through the alteration of the structure and abundance of the phytoplankton community, upon which many zooplankton depend for food. Predation from the exotic cladocerans *Bythotrephes longimanus* and *Cercopagis pengoi* may also have an impact on zooplankton abundance and community composition. *Bythotrephes* has been in the Great Lakes for approximately twenty years, and is suspected to have had a major impact on zooplankton community structure. *Cercopagis pengoi* was first noted in Lake Ontario in 1998, and has now spread to the other lakes, although in much lower densities. Continuing changes in predation pressure from planktivorous fish may also impact the system

Management Implications

Continued monitoring of the offshore zooplankton communities of the Great Lakes is critical, particularly considering the current expansion of the range of the non-native cladoceran *Cercopagis* and the probability of future invasive zooplankton and fish species.

Comments from the author(s)

Currently the most critical need is for the development of quantitative, objective criteria that can be applied to the zooplankton indicator. The applicability of current metrics to the Great Lakes is largely unknown, as are the limits that would correspond to acceptable ecosystem health.

The implementation of a long-term monitoring program on the Canadian side is also desirable to expand both the spatial and the temporal coverage currently provided by American efforts. Since the interpretation of various indices is dependent to a large extent upon the sampling methods employed, coordination between these two programs, both with regard to sampling dates and locations, and especially with regard to methods, would be highly recommended.

Acknowledgments

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Ora Johannsson, Fisheries and Oceans Canada, Burlington, Ontario Canada.

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Figure 2. Average percentage of calanoid copepods (by abundance) in crustacean zooplankton communities from Great Lakes offshore stations sampled in August of each year. Samples were collected with 153µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Line at 50% level is the suggested criterion for oligotrophic lakes. Source: U.S. Environmental Protection Agency, Great Lakes National Program Office.

Figure 3. Average individual mean lengths of crustacean zooplankton in the Great Lakes in May and August. Length estimates were generated from data collected with 153µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Values are the indicate arithmetic averages of all sites sampled. Line at 0.8 mm is the suggested criterion for balanced fish community. Source: U.S. Environmental Protection Agency, Great Lakes National Program Office.

Figure 4. Trend in Jun27-Sep30 mean zooplankton length: NYDEC data (circles) collected with 153µm mesh net, DFP data (diamonds) converted from 64µm to 153µm mesh equivalent. Open symbols = offshore, solid symbols = nearshore (<12m). 1985-1988 are means +/- 1 S.E. Source: Johannsson *et al*. 1999.

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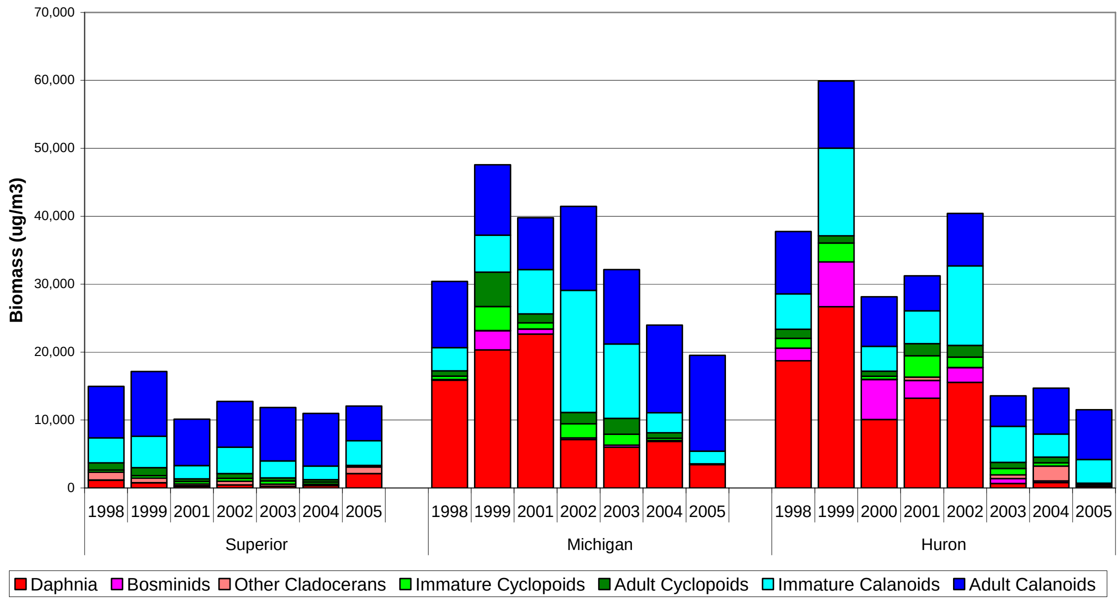

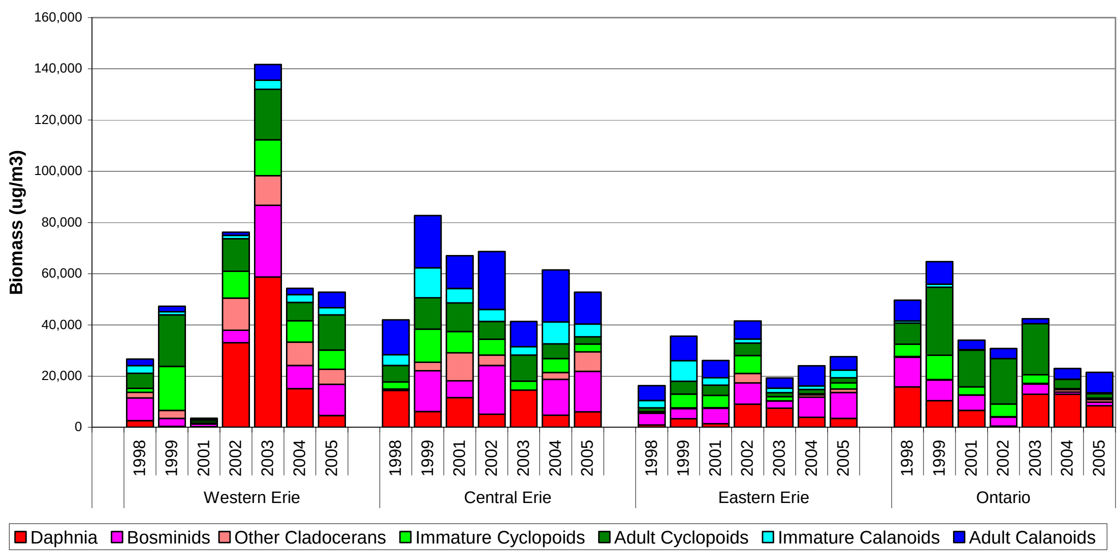

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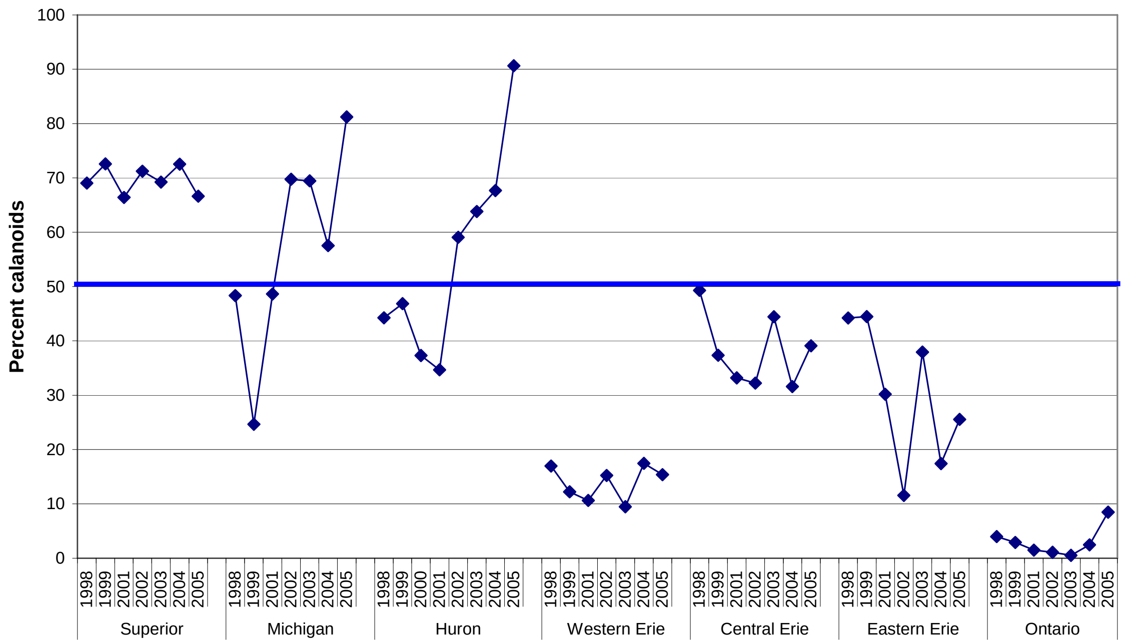

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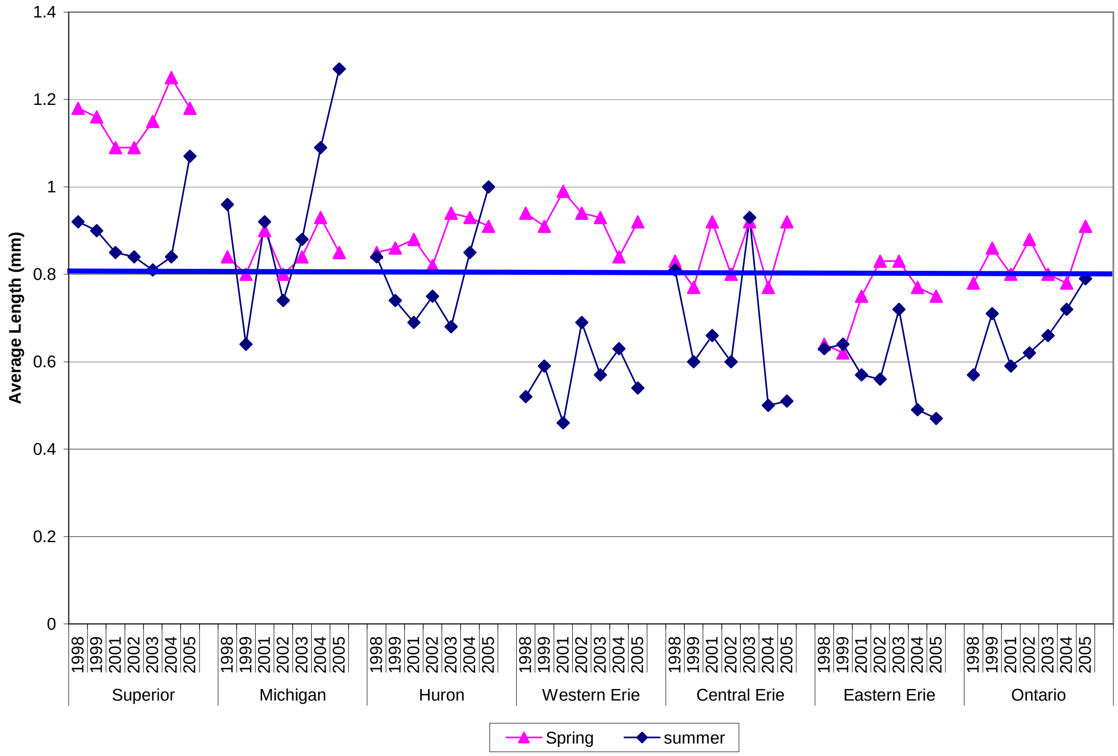

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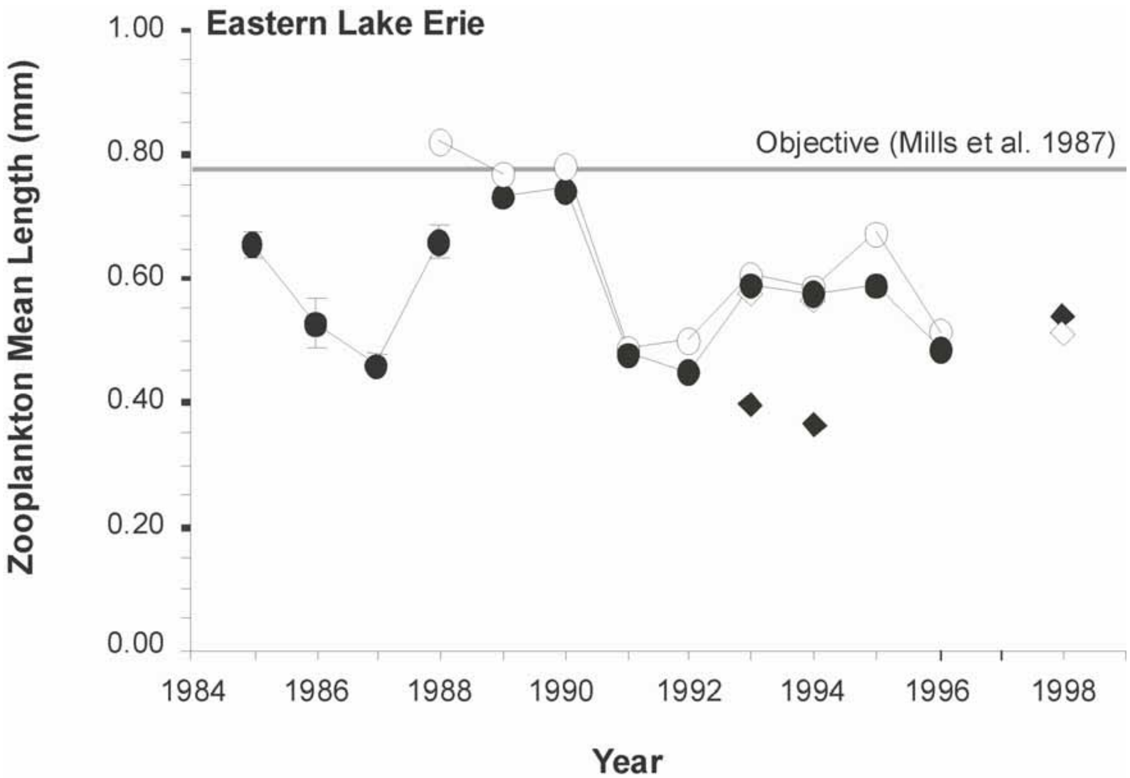

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Atmospheric Deposition of Toxic Chemicals
Indicator #117

Overall Assessment

Status:	**Mixed**
Trend:	**Improving for polychlorinated biphenyls (PCBs), banned organochlorine pesticides, and dioxins and furans** **Unchanging or slightly improving for polycyclic aromatic hydrocarbons (PAHs) and mercury**
Primary Factors Determining Status and Trend	**Mixed since different chemical groups have different trends over time; levels in cities can be much higher than in rural areas**

Lake-by-Lake Assessment
The indicator status is **mixed** for all Lakes. Levels of PBT chemicals in air tend to be lower over Lakes Superior and Huron than over the other three Lakes (which are more impacted by human activity), but their surface area is larger, resulting in a greater importance of atmospheric inputs.

While concentrations of some of these substances are very low at rural sites, they may be much higher in "hotspots" such as urban areas. Lakes Michigan, Erie, and Ontario have greater inputs from urban areas. The Lake Erie station tends to have higher levels than the other remote master stations, most likely since it is located closer to an urban area (Buffalo, NY) than the other master stations; it may also receive some influence from the East Coast of the U.S.

In general for PBT chemicals, atmospheric inputs dominate for Lakes Superior, Huron, and Michigan due to their large surface areas (Strachan and Eisenreich 1991, Kreis 2005). Connecting channel inputs dominate for Lakes Erie and Ontario, which have smaller surface areas.

Purpose
- To estimate the annual average loadings of persistent bioaccumulative toxic (PBT) chemicals from the atmosphere to the Great Lakes;
- To determine trends over time in contaminant concentrations;
- To infer potential impacts of toxic chemicals from atmospheric deposition on human health and the Great Lakes aquatic ecosystem; and
- To track the progress of various Great Lakes programs toward virtual elimination of toxic chemicals to the Great Lakes.

Tracking atmospheric inputs is important since the air is a primary pathway by which PBTs reach the Great Lakes. Once PBTs reach the Great Lakes, they can bioaccumulate in fish and other wildlife and cause fish consumption advisories.

Ecosystem Objective
The Great Lakes Water Quality Agreement (GLWQA) and the Binational Toxics Strategy both state the virtual elimination of toxic substances in the Great Lakes as an objective. Additionally, GLWQA General Objective (d) states that the Great Lakes should be free from materials entering

the water as a result of human activity that will produce conditions that are toxic to human, animal, or aquatic life.

State of the Ecosystem

The Integrated Atmospheric Deposition Network (IADN) consists of five master sampling sites, one near each of the Great Lakes, and several satellite stations. This joint United States-Canada project has been in operation since 1990. Since that time, thousands of measurements of the concentrations of PCBs, pesticides, PAHs and trace metals have been made at these sites. Concentrations are measured in the atmospheric gas and particle phases and in precipitation. Spatial and temporal trends in these concentrations and atmospheric loadings to the Great Lakes can be examined. Data from other networks are used here to supplement the IADN data for mercury, dioxins and furans.

PCBs. Concentrations of gas-phase PCBs (ΣPCB) have generally decreased over time at the master stations (Figure 1). ΣPCB is a suite of congeners that make up most of the PCB mass and represent the full range of PCBs. Some increases are seen during the late 1990s for Lakes Michigan and Erie and during 2000-2001 for Lake Superior. These increases remain unexplained, although there is some evidence of connections with atmospheric circulation phenomena such as El Nino (Ma *et al*. 2004a). Levels decrease again by 2002. It is assumed that PCB concentrations will continue to decrease slowly. It should be noted that PCBs in precipitation samples at the rural master stations are nearing levels of detection.

The Lake Erie site consistently shows relatively elevated ΣPCB concentrations compared to the other master stations. Back-trajectory analyses have shown that this is due to possible influences from upstate New York and the East Coast (Hafner and Hites 2003). Figure 2 shows that ΣPCB concentrations at urban satellite stations in Chicago and Cleveland are about fifteen and ten times higher, respectively, than at the remote master stations at Eagle Harbor (Superior) and Sleeping Bear Dunes (Michigan).

Pesticides. In general, concentrations of banned or restricted pesticides measured by the IADN (such as hexachlorocyclohexane [a-HCH] and DDT) are decreasing over time in air and precipitation (Sun *et al*. 2006a, Sun *et al*. submitted). Concentrations of chlordane are about ten times higher at the urban stations than at the more remote master stations, most likely due to the use of chlordane as a termiticide in buildings. Dieldrin shows a similar urban elevation; this pesticide was also used as a termiticide until 1987, after all other uses were banned in 1974. Current-use pesticide endosulfan shows mixed trends, with significant decreases at some sites in some phases, but no trends at other sites. Concentrations of endosulfan were generally higher in the summer, following application of this current-use pesticide (Sun *et al*. submitted).

PAHs. In general, concentrations of polycyclic aromatic hydrocarbons can be roughly correlated with population, with highest levels in Chicago and Cleveland, followed by the semi-urban site at Sturgeon Point, and lower concentrations at the other remote master stations. In general, PAH concentrations in Chicago and Cleveland are about ten to one hundred times higher than at the master stations.

Concentrations of PAHs in the particle and gas phase are decreasing at Chicago, with half-lives ranging from 3-10 years in the vapor phase and 5-15 years in the particle phase. At the other sites, most gas phase PAH concentrations showed significant, but slow long-term decreasing trends (>15 years). For most PAHs, decreases on particles and in precipitation were only found at Chicago (Sun *et al*. 2006b, Sun *et al*. submitted).

An example of a PAH is benzo[a]pyrene (BaP), a PAH, is produced by the incomplete combustion of almost any fuel and is a probable human carcinogen. Figure 3 shows the annual average particle-phase concentrations of BaP.

Dioxins and Furans. Concentrations of dioxins and furans have decreased over time (Figure 4) with the largest declines in areas with the highest concentrations (unpublished data, T. Dann, Environment Canada 2006).

Mercury. Data from the Canadian Atmospheric Mercury Network (CAMNet) for the IADN stations at Egbert, Point Petre, and Burnt Island show decreases in total gaseous mercury (TGM) concentrations between 1995 and 2004, with more of the decrease occurring in the 2000-2004 time period (Figure 5). Median TGM concentrations decreased by 7-19% from 2000 to 2004 for those stations (Temme *et al*. 2006).

Data from the Mercury Deposition Network (MDN) show that concentrations of mercury in precipitation are decreasing for much of the U.S., but there is no trend for the stations in the upper Midwest (Gay *et al*. 2006).

PBDEs. Total PBDE concentrations during 2003-2004 were in the single pg/m^3 range for the rural master stations and in the 50-100 pg/m^3 range for the urban stations (Venier 2006). This is lower than total PCB levels, which are generally in the 10s to 100s of pg/m^3 range. A meta-analysis of PBDE concentrations in various environmental compartments and biota worldwide revealed exponentially increasing concentrations with doubling times of about 4-6 years and higher levels in North America than in Europe (Hites 2004). US manufacturers of penta- and octa-PBDEs phased out production in 2004, but deca-PBDEs are still being produced. Future data will confirm whether PBDEs increase or decrease in the air of the Great Lakes.

Loadings. An atmospheric loading is the amount of a pollutant entering a lake from the air, which equals wet deposition (rain) plus dry deposition (falling particles) plus gas absorption into the water minus volatilization out of the water. Absorption minus volatilization equals net gas exchange, which is the most significant part of the loadings for many semi-volatile PBT pollutants. For many banned or restricted substances that IADN monitors, net atmospheric inputs to the lake are headed toward equilibrium; that is, the amount going into the lake equals the amount volatilizing out. Current-use pesticides, such as g-HCH (lindane) and endosulfan, as well as PAHs and trace metals, still have net deposition from the atmosphere to the Lakes.

A report on the atmospheric loadings of these compounds to the Great Lakes for data through 2004 will be published in late 2006 or early 2007. It will be available online at: http://www.epa.gov/glnpo/monitoring/air/iadn/iadn.html.
To receive a hardcopy, please contact one of the agencies listed at the end of this report.

Pressures

Atmospheric deposition of toxic compounds to the Great Lakes is likely to continue into the future. The amount of compounds no longer in use, such as most of the organochlorine pesticides, may decrease to undetectable levels, especially if they are phased out in developing countries, as is being called for in international agreements.

Residual sources of PCBs remain in the U.S. and throughout the world; therefore, atmospheric deposition will still be significant at least decades into the future. PAHs and metals continue to be emitted and therefore concentrations of these substances may not decrease or will decrease very slowly depending on further pollution reduction efforts or regulatory requirements. Even though emissions from many sources of mercury and dioxin have been reduced over the past decade, both pollutants are still seen at elevated levels in the environment. This problem will continue unless the emissions of mercury and dioxin are reduced further.

Atmospheric deposition of chemicals of emerging concern, such as brominated flame retardants and other compounds that may currently be under the radar, could also serve as a future stressor on the Great Lakes. Efforts are being made to screen for other chemicals of potential concern, with the intent of adding such chemicals to Great Lakes monitoring programs given available methods and sufficient resources.

Management Implications

In terms of in-use agricultural chemicals, such as lindane, further restrictions on the use of these compounds may be warranted. Transport of lindane to the Great Lakes following planting of lindane-treated canola seeds in the Canadian prairies has been demonstrated by modellers (Ma *et al*. 2004b). On January 1, 2005, Canada withdrew registration of lindane for agricultural pest control; lindane is still registered for use in the U.S.

Controls on the emissions of combustion systems, such as those in factories and motor vehicles, could decrease inputs of PAHs to the Great Lakes' atmosphere.

Although concentrations of PCBs continue to decline slowly, somewhat of a "leveling-off" trend seems to be occurring in air, fish, and other biota as shown by various long-term monitoring programs. Remaining sources of PCBs, such as contaminated sediments, sewage sludge, and in-use electrical equipment, may need to be addressed more systematically through efforts like the Canada-U.S. Binational Toxics Strategy and national regulatory programs in order to see more significant declines. Many such sources are located in urban areas, which is reflected by the higher levels of PCBs measured in Chicago and Cleveland by IADN, and by other researchers in other areas (Wethington and Hornbuckle 2005; Totten *et al*. 2001). Research to investigate the significance of these remaining sources is underway. This is important since fish consumption advisories for PCBs exist for all five Great Lakes.

Progress has been made in reducing emissions of dioxins and furans, particularly through regulatory controls on incinerators. Residential garbage burning (burn barrels) is now the largest current source of dioxins and furans (Environment Canada and U.S. Environmental Protection Agency 2003). Basin- and nationwide efforts are underway to eliminate emissions from burn barrels.

Regulations on coal-fired electric power plants, the largest remaining source of anthropogenic mercury air emissions, will help to decrease loadings of mercury to the Great Lakes.

Pollution prevention activities, technology-based pollution controls, screening of in-use and new chemicals, and chemical substitution (for pesticides, household, and industrial chemicals) can aid in reducing the amounts of toxic chemicals deposited to the Great Lakes. Efforts to achieve reductions in use and emissions of toxic substances worldwide through international assistance and negotiations should also be supported, since PBTs used in other countries can reach the Great Lakes through long-range transport.

Continued long-term monitoring of the atmosphere is necessary in order to measure progress brought about by toxic reduction efforts. Environment Canada and USEPA are currently adding dioxins and PBDEs to the IADN as funding allows. Mercury monitoring at Canadian stations is being conducted through the CAMNet. Additional urban monitoring is needed to better characterize atmospheric deposition to the Great Lakes.

Acknowledgments
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Figure 2. Gas Phase PCB concentrations for rural sites versus urban areas.
Source: IADN Steering Committee, unpublished, 2006.

Figure 3. Annual Average Particulate Concentrations of Benzo(a)pyrene.
Source: IADN Steering Committee, unpublished, 2006.

Figure 4. Concentrations of dioxins and furans expressed as TEQ (Toxic Equivalent) in fg/m3 in Windsor, Ontario.
Source: Environment Canada National Air Pollution Surveillance (NAPS) network, unpublished, 2006.

Figure 5. Trends from 2000 to 2004 for median concentrations of total gaseous mercury (ng/m^3) at CAMNet stations.
Source: Temme *et al*. 2006.

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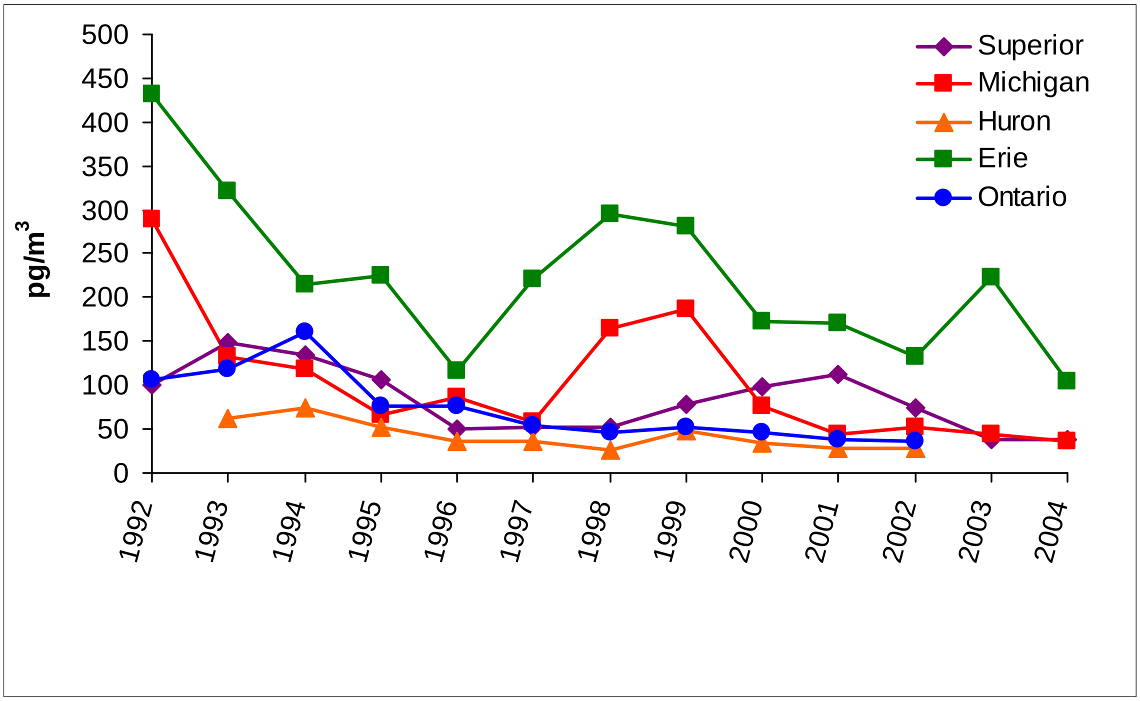

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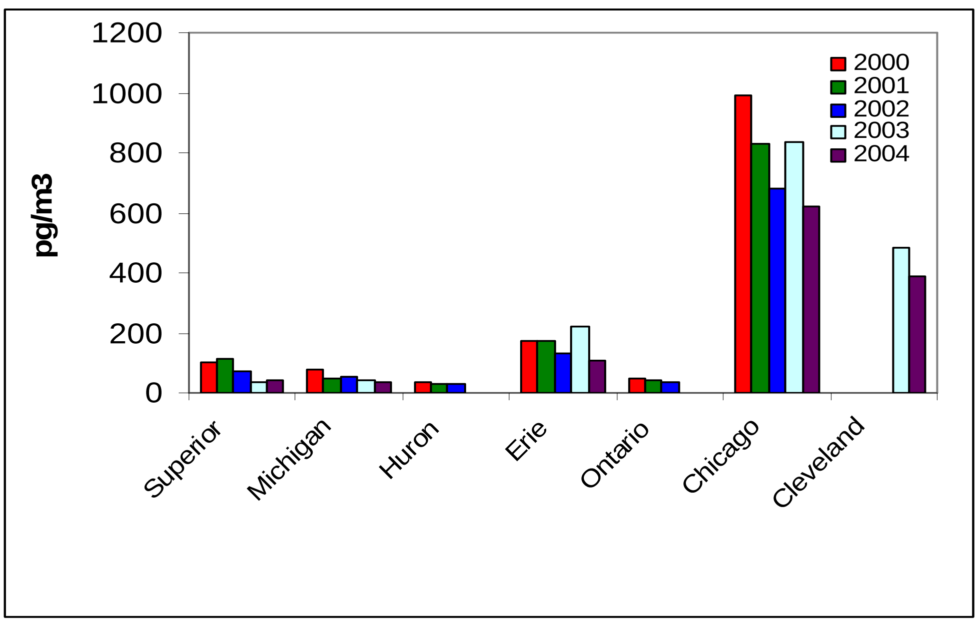

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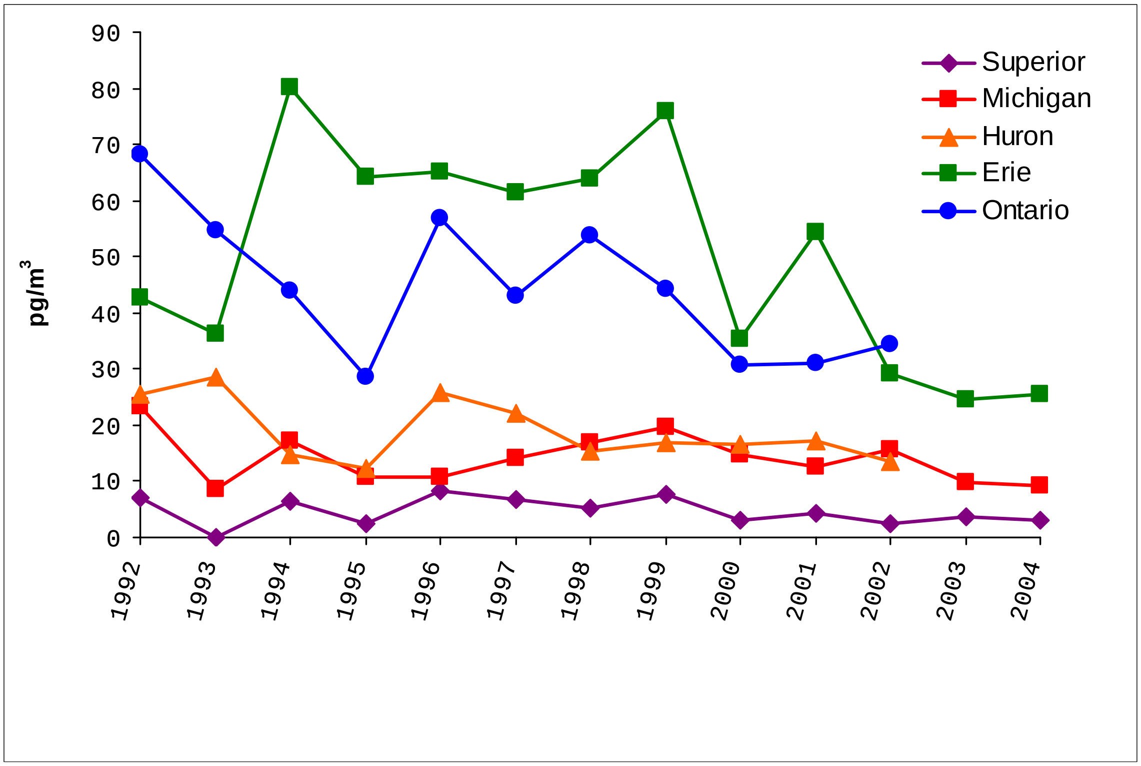

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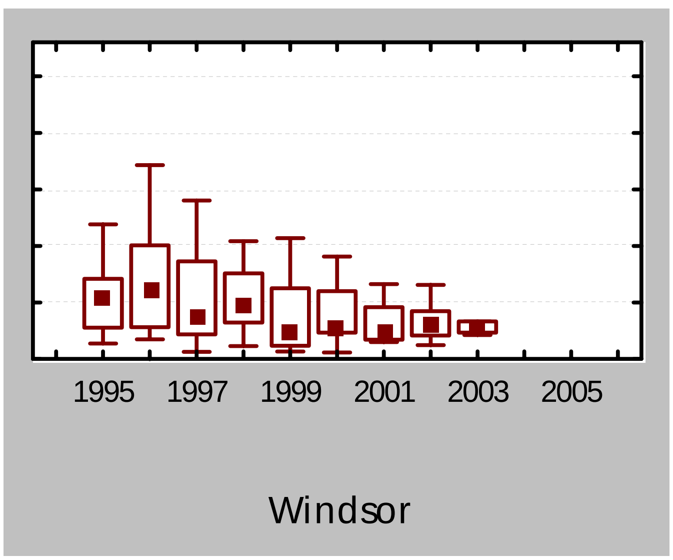

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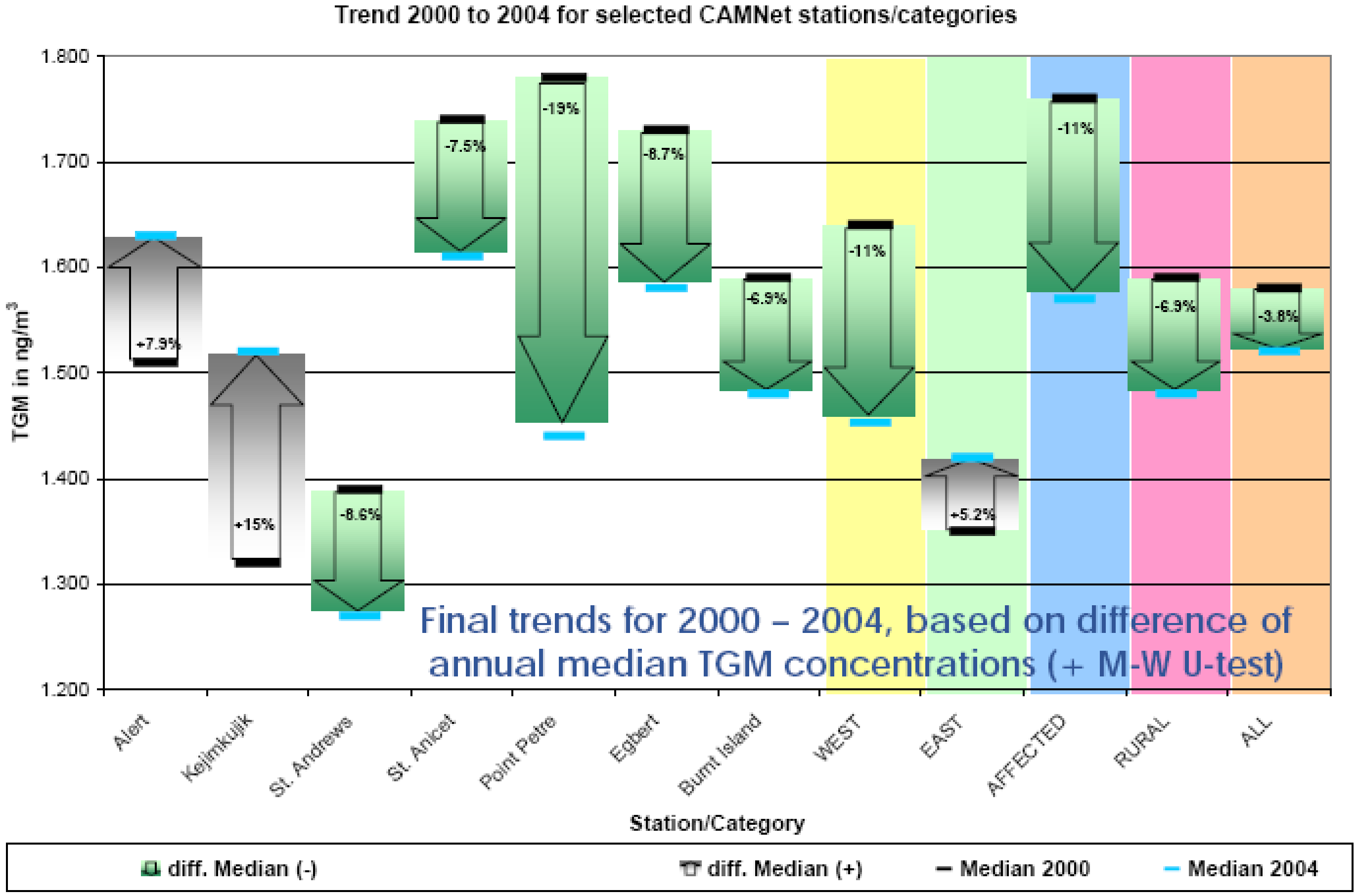

Figure 5. Trends from 2000 to 2004 for median concentrations of total gaseous mercury (ng/m^3) at CAMNet stations.
Source: Temme *et al*. 2006

Toxic Chemical Concentrations in Offshore Waters
Indicator #118

Overall Assessment

Status: **Mixed**

Trend: **Undetermined**

Primary Factors Determining Status and Trend: **Data for this indicator is not available system-wide for all chemicals.**

Concentrations of most organic compounds are low and are declining in the open waters of the Great Lakes, indicating progress in the reduction of persistent toxic substances. Insufficient data are available at this time to make a robust determination of the recent trend in concentrations of all compounds.

Generally, organochlorine pesticide concentrations exhibit a north to south gradient from lowest to highest (Superior<Huron<Ontario<Erie) based on work completed by Environment Canada. Exceptions to this pattern do exist; for example, compounds that are primarily distributed by atmospheric deposition rather than point sources, such as Lindane and Chlordane, are found at higher concentrations in the north. However, distributions and concentrations of most substances reflect sources from agricultural land use practices (i.e., higher concentrations in the lower Great Lakes where agriculture dominates). Direct discharges of currently used pesticides have greatly diminished so that indirect discharge is the more likely current source. Indirect discharges include atmospheric deposition, agricultural land runoff, leaching of discarded stocks, and resuspension of contaminated sediments (Kannan *et al* 2006).

Mercury concentrations overall are very low, and concentrations in the open lake areas are currently below the U.S. EPA's Great Lakes Initiative (GLI) water quality criterion of 1.3 ng/L. However, higher concentrations are observed in the western basin of Lake Erie in particular, and in some harbours and major urban areas as well (e.g., Detroit, Hamilton, Duluth/Superior Harbor, Rochester, Chicago) (Figure 1). Some samples from these urban areas exceed the GLI water quality criterion for protection of wildlife.

The distribution of PCBs in the Great Lakes indicates higher concentrations near historical, localized sources. Concentrations in offshore waters are lower than nearshore, and concentrations in the upper Great Lakes are lower than the lower Great Lakes. Reductions are largely due to the ban of PCBs and the subsequent control of point sources.

The spatial distribution of PAHs reflects the major source from the burning of fossil fuels. Concentrations of PAHs are therefore higher in the lower lakes, where usage is greater. The lighter PAHs are also ubiquitous in the upper Great Lakes, but their concentrations are much lower.

Little or no information is currently available for some compounds, such as dioxins, in offshore waters. Concentrations of these compounds are extremely low and difficult to detect in lake water samples. It may be more appropriate to measure them in fish and/or sediment samples. Information about compounds of new and emerging concern is being assessed and information should be available for a future SOLEC update.

Lake-by-Lake Assessment

Lake Superior

Status: Fair

Trend: Undetermined

Primary Factors Determining Status and Trend: Thirteen of a possible 21 organochlorines were detected in Lake Superior and their concentrations were generally very low. Their presence is most likely due to atmospheric deposition because the traditional sources (row-crop agriculture and urban land uses) are low in this basin. For example, concentrations of the insecticide Dieldrin (Figure 2) reflect its usage in the agricultural communities of the southern Great Lakes basin and are low in Lake Superior (2005: open lake average = 0.11 ng/L). In contrast, concentrations of Lindane (Figure 3), which was previously used in North American agriculture, reflect greater atmospheric deposition in the north (2005: open lake average = 0.31 ng/L).

Mercury concentrations in Lake Superior were very low offshore (2005 open lake average 0.41 ng/L), with higher concentrations near Thunder Bay and Duluth. With the exception of one station near Duluth, all samples met the US EPA Great Lakes Initiative (GLI) water quality criterion for protection of wildlife of 1.3 ng/L.

PAHs are present throughout the Lake at extremely low concentrations. Concentrations were many orders of magnitude below Ontario Water Quality Guidelines. For example, the open lake average concentration of Phenanthrene (Figure 4) was 0.03 ng/L and the Ontario Guideline is 30 ng/L.

Lake Michigan

Status: Fair

Trend: Undetermined

Primary Factors Determining Status and Trend: Preliminary data from 2004 indicate that concentrations of PCBs and organochlorine pesticides have either decreased slightly or remained constant since the mid-1990s, following a decrease in the 1970s through the early 1990s. 2005 total mercury concentrations were all below the U.S. EPA's Great Lakes Initiative (GLI) water quality criterion for protection of wildlife of 1.3 ng/L. Atrazine concentrations in the open lake waters were consistent across Lake Michigan stations with an average concentration ranging from 33 to 48 ng/L between 1994 and 2000; this is more than 50 times below the maximum concentration allowed for drinking water

(Kannan *et al* 2006).

Lake Huron

Status: Fair

Trend: Undetermined

Primary Factors Determining Status and Trend

In 2004, 16 of a possible 21 organochlorines were detected in Lake Huron, but only 11 were commonly found. Commonly found OCs included a-HCH, lindane, dieldrin, and g-chlordane. The concentrations were generally low, reflecting historical or diffuse sources. For example, average concentrations of dieldrin in 2004 were 0.08 ng/L in Lake Huron and 0.07 ng/L in Georgian Bay. These concentrations were lower than those found in the other Great Lakes and are well below the Ontario Water Quality Objective of 1.0 ng/L.

Mercury concentrations in Lake Huron and Georgian Bay were low (2005 open lake average: Lake Huron 0.58 ng/L, Georgian Bay 0.33 ng/L). The concentrations at all open lake stations were below the USEPA's Great Lakes Initiative (GLI) water quality criterion for protection of wildlife of 1.3 ng/L (Figure 1), and only one nearshore station in Georgian Bay exceeded this level.

PAH concentrations in Lake Huron and Georgian Bay are very low. Of the 20 and 19 PAH compounds found in Lake Huron and Georgian Bay, respectively, five were detected only within the North Channel (Dibenzo(a,h)antracene, Perylene, Benzo(a)pyrene, Anthracene, and 2-Chloronaphthalene). The open lake average concentration of Phenanthrene (Figure 4) was 0.08 ng/L in Lake Huron and 0.13 ng/L in Georgian Bay, well below the Ontario guideline of 30 ng/L.

Lake Erie

Status: Mixed

Trend: Undetermined

Primary Factors Determining Status and Trend

In 2004, Environment Canada's Great Lakes Surveillance Program detected 15 of a possible 21 organochlorine compunds in Lake Erie; 10 of these were commonly found, including a-HCH, HCB, Lindane and Dieldrin. Concentrations of most compounds were highest in the shallow western basin and much lower in the central and eastern basins. An exception is Lindane, which showed similar concentrations in all three basins. Almost all Canadian sources of Lindane to the Great Lakes are from the Canadian prairies (Ma *et al* 2003). Similar results were found in 1998 by Marvin *et al*. (2004). Between 1998 and 2004 average lakewide Lindane concentrations fell (2004: 0.16 ng/l; 1998: 0.32 ng/l) indicating a possible downward trend. Key contributors of hexachlorobenzene and octachlorostyrene were identified in the St. Clair River (Marvin *et al* 2004).

The intensively-farmed agricultural and urban lands draining into Lake Erie and Lake St. Clair are a major contributor of pesticides and other contaminants to the Great Lakes. In these watersheds, approximately 75%

of the land use is agriculture and about 40% of the Great Lakes population resides here. Pesticides were detected in every tributary monitored between 1996 and 1998 (Kannan *et al* 2006). Some tributaries contained as many as 18 different pesticides; among the highest counts for any watershed monitored in North America.

Mercury concentrations in 2005 in Lake Erie were the highest of the Great Lakes and reflected a decreasing concentration from west to east (average concentrations 2.53 ng/L in the western basin, 0.52 ng/L in the central basin, and 0.49 ng/L in the eastern basin). Higher concentrations (above 3.0 ng/L) were found near the mouths of the Detroit and Maumee rivers. Concentrations at all stations in the western basin, as well as some stations in the central and eastern basins, exceeded the GLI mercury criterion of 1.3 ng/L.

PAH concentrations and distributions reflected urban source areas on the Lake and upstream sources within the St. Clair River – Detroit River corridor. The highest concentrations of most PAHs were found in the western basin, and near the mouth of the Detroit River in particular. For example the phenanthrene concentration (Figure 4) at the mouth of the Detroit River was 2.5 ng/L, whereas the overall Lake average was 0.59 ng/L, an almost 5-fold difference.

Lake Ontario

Status: Mixed

Trend: Undetermined

Primary Factors Determining Status and Trend: Seventeen of a possible 21 OC pesticides were detected in Lake Ontario waters in 2005. Dieldrin, lindane, and a-HCH were routinely found. Probable sources of these compounds include a combination of historical watershed uses, upstream loadings (e.g. the Niagara River) and atmospheric deposition. Concentrations of many parameters were intermediate compared to the upper Great Lakes (which generally had lower concentrations) and Lake Erie (which generally had higher concentrations, especially in the western basin). Within Lake Ontario, spatial trends were reflective of localized (predominantly urban) sources.

Mercury concentrations in Lake Ontario were low in the offshore areas (average 0.48) and higher in the nearshore (average 0.80 ng/L). Spatial trends were reflective of localized sources (e.g. higher values in Toronto and Hamilton, Ontario and Rochester and Oswego, New York), but only samples taken from Hamilton Harbour exceeded the GLI objective of 1.3 ng/L for mercury.

PAH distribution and concentrations reflect urban source areas on the Lake (e.g., Rochester NY, Niagara River, and Hamilton, Ontario). All offshore concentrations were below Ontario Water Quality Guidelines.

Purpose
This indicator reports on concentrations of priority toxic chemicals in offshore waters, and, by comparison to criteria for the protection for aquatic life and human health, infers the potential for impacts to the health of the Great Lakes aquatic ecosystem. The indicator can be used to infer the progress of virtual elimination programs as well.

Ecosystem Objective
The Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human, animal, or aquatic life (GLWQA, Article III(d)).

State of the Ecosystem
Many toxic chemicals are present in the Great Lakes and it is impractical to summarize the spatial and temporal trends of them all within a few pages. For more information on spatial and temporal trends in toxic contaminants in offshore waters, the reader is referred to Marvin *et al*. (2004), Kannan *et al*. (2006), and *Trends in Great Lakes Sediments and Surface Waters* in Chapter 8 of the Great Lakes Binational Toxics Strategy 2004 Progress report.

Surveys conducted between 1992 and 2000 (Marvin *et al*), and between 2004-2005 (Environment Canada unpublished data) on Lakes Superior, Huron, Erie and Ontario showed that concentrations of most organic compounds are low (i.e., below the most stringent water quality guidelines) and declining in the open waters of the Great Lakes. The decline in the concentration of banned organochlorine pesticides has leveled off since the mid-1980s and current rates of decline are slow.

Dieldrin, a-HCH, lindane (g-HCH), and heptachlor epoxide were the only organochlorine pesticide compounds routinely detected in Lakes Superior, Erie and Ontario (Marvin *et al*. 2004). The in-use herbicides atrazine and metolachlor were ubiquitous (Marvin *et al*. 2004). An example of the spatial distribution of dieldrin using 2004/05 data is provided in Figure 2.

Many organic compounds (such as PCBs, hexachlorobenzene, octachlorostyrene, and DDT) show a spatial pattern that indicates higher concentrations near historical, localized sources. Currently emitted compounds, such as PAHs and mercury, which are released during fossil fuel combustion, also show spatial patterns that are indicative of sources. Concentrations of the heavier PAHs, which are not as subject to atmospheric transport due to their partitioning to particles, are highest in the lower Great Lakes, where human populations are greater.

Management Implications
Management efforts to control inputs of organochlorine pesticides have resulted in decreasing concentrations in the Great Lakes; however, historical sources for some compounds still appear to affect ambient concentrations in the environment. Further reductions in the input of OC pesticides are dependent, in part, on controlling indirect inputs such as atmospheric deposition and surface runoff. Monitoring programs should increase measurement of the major in-use pesticides, of which currently only half are monitored. The additive and synergetic effects of pesticide mixtures should be examined more closely, since existing water quality criteria have been development for individual pesticides only (Kannan *et al* 2006).

Beginning in 1986, Environment Canada has conducted toxic contaminant monitoring in the shared waters of the Great Lakes. Recently, Environment Canada has developed new measurement techniques and has invested in an ultra-clean laboratory in order to more accurately measure these trace concentrations of pollutants in the surface waters of the Great Lakes. The data presented here represent the results of this new methodology. Data is available for all of the shared waters, although only partial coverage of Lake Ontario has been analyzed to date. The analyte list includes PCBs (as congeners), organochlorines, polycyclic aromatic hydrocarbons (PAHs), trace metals including mercury, as well as a limited number of in-use pesticides and other compounds of emerging concern.

In 2003, USEPA initiated a monitoring program for toxics in offshore waters. EPA's spatial coverage is more limited than the Canadian program, focusing mainly on Lake Michigan, but the analyte list is more comprehensive and includes PCBs, organochlorine pesticides, toxaphene, dioxins/furans, PBDEs, selected PAHs, mercury, and perfluorinated compounds. Information from the USEPA is currently available for Lake Michigan for many organic compounds. Different measurement and analytical techniques are used, but good agreement with Canadian information is achieved for some parameters. Future efforts will need to focus on comparisons of the analytical methodologies used and the results obtained. In 2006, some work to this end is being initiated by the parties in Lake Michigan.

Efforts need to be maintained to identify and track the remaining sources and explore opportunities to accelerate their elimination (e.g. The Great Lakes Binational Toxics Strategy). Targeted monitoring to identify and track down local sources of LaMP critical pollutants is being conducted in many Great Lakes tributaries. However, an expansion of the track down program should be considered to include those chemicals whose distribution suggests localized influences.

Chemicals such as endocrine disrupting chemicals, in-use pesticides, and pharmaceuticals are emerging issues. The agencies' environmental researchers are working with the monitoring groups to include compounds of emerging concern in Great Lakes Surveillance cruises. For example, in-use pesticides and a suite of pharmaceuticals are being measured in each of the Great Lakes between 2005 and 2007.

Comments from the author(s)
Data for Lakes Superior, Huron, Erie and Ontario are from Environment Canada's Great Lakes Water Quality Monitoring and Surveillance Program. Data for Lake Michigan are from the US EPA's Great Lakes Aquatic Contaminant Surveillance (GLACS) program (Principal Investigators: Dr. Matt Simcik of the University of Minnesota and Dr. Jeff Jeremiason of Gustavus Adolphus College).

Lake Ontario 2005 data for PAHs and OC pesticides reflects sampling conducted in the western half of the lake only.

Acknowledgments
Authors: Jennifer Vincent and Alice Dove, Environment Canada, Burlington, ON, Melissa Hulting, Great Lakes National Program Office, USEPA, Chicago, IL.

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Source: Environment Canada's Great Lakes Water Quality Surveillance Program, Burlington, Ontario and U.S. Environmental Protection Agency's Great Lakes National Program Office, Chicago, Illinois.

Figure 2. Great Lakes 2004/05 Open Lake, Spring Cruise, Concentrations of Dieldrin (ng/L). Lake Ontario data for western half of the lake only.
Source: Environment Canada's Great Lakes Water Quality Surveillance Program, Burlington, Ontario.

Figure 3. Great Lakes 2004/05 Open Lake, Spring Cruise, Concentrations of Lindane (ng/L). Lake Ontario data for western half of the lake only.
Source: Environment Canada's Great Lakes Water Quality Surveillance Program, Burlington, Ontario.

Figure 4. Great Lakes 2004/05 Open Lake, Spring Cruise, Concentrations of Phenanthrene (ng/L).
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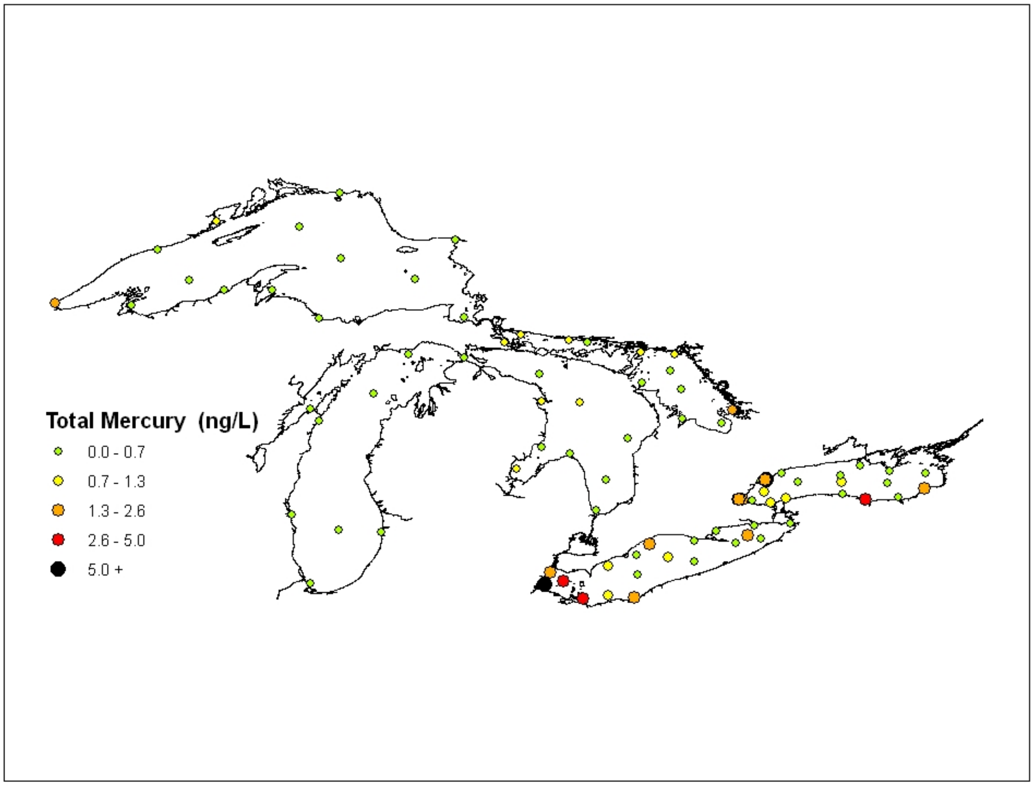

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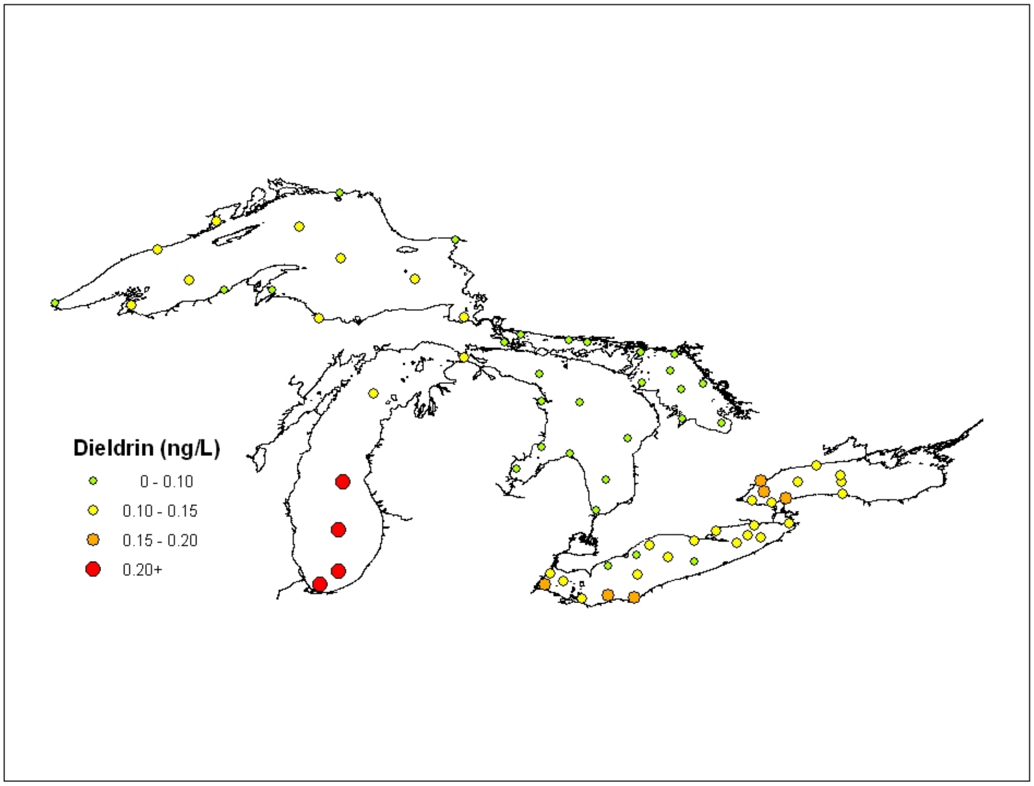

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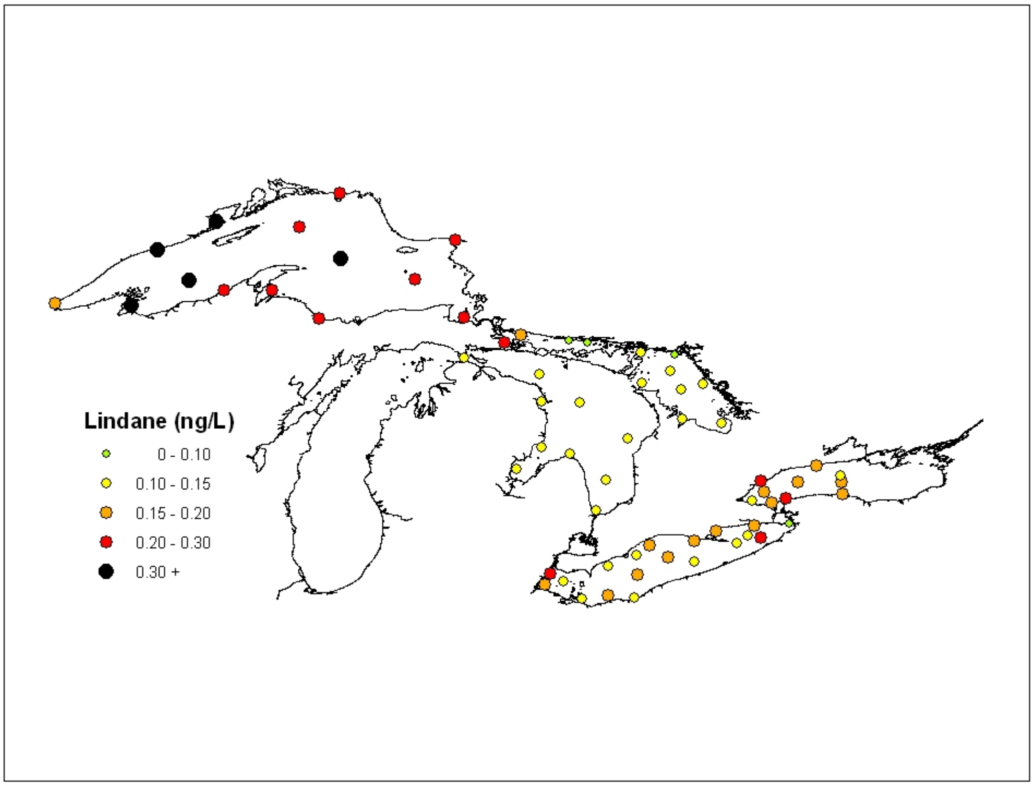

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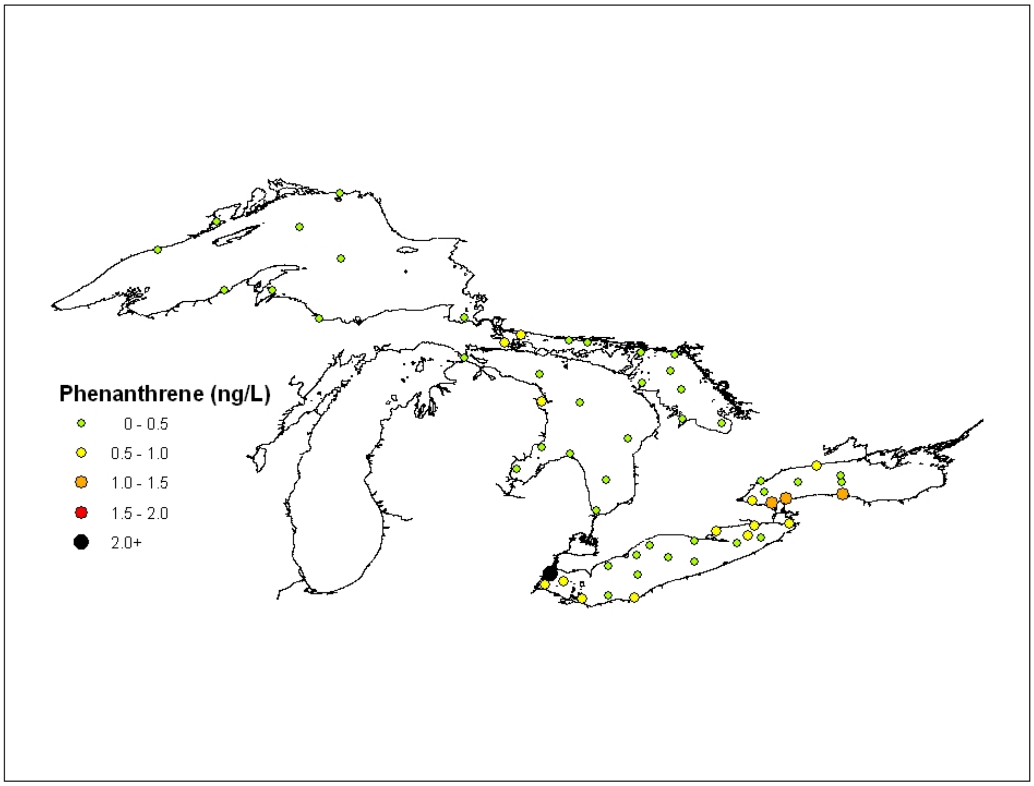

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Concentrations of Contaminants in Sediment Cores

Indicator #119

Overall Assessment

Status:	**Mixed**
Trend:	**Improving/Undetermined**
Primary Factors Determining Status and Trend	**There have been significant declines over the past three decades in concentrations of many contaminants including PCBs, DDT, lead, and mercury. Knowledge is lacking regarding the occurrence of many new contaminants including BFRs and fluorinated surfactants.**

Lake-by-Lake Assessment

Lake Superior

Status: Mixed
Trend: Improving/Undetermined

Lake Michigan

Status: Mixed
Trend: Improving/Undetermined

Lake Huron

Status: Mixed
Trend: Improving/Undetermined

Lake Erie

Status: Mixed
Trend: Improving/Undetermined

Lake Ontario

Status: Mixed
Trend: Improving/Undetermined

Purpose

•To infer potential harm to aquatic ecosystems from contaminated sediments by comparing contaminant concentrations to available sediment quality guidelines;
•To infer progress towards virtual elimination of toxic substances in the Great Lakes by assessing surficial sediment contamination and contaminant concentration profiles in sediment cores from open lake and, where appropriate, Areas of Concern index stations, and;
•To determine the occurrence, distribution, and fate of new chemicals in Great Lakes sediments.

Ecosystem Objective

The Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human health, animal, or aquatic life (Great Lakes Water Quality Agreement (GLWQA), Article III(d)). The GLWQA and the Great Lakes Binational Toxics Strategy both state the virtual elimination of toxic substances to the Great Lakes as an objective.

State of the Ecosystem

Sediment Quality Index

A sediment quality index (SQI) has been developed that incorporates three elements: scope – the percent of variables that did not meet guidelines; frequency – the percent of failed tests relative to the total number of tests in a group of sites; and amplitude – the magnitude by which the failed variables exceeded guidelines. A full explanation of the SQI derivation process and a possible classification scheme based on the SQI score (0 – 100, poor to excellent) is provided in Grapentine *et al*. (2002). Generally, the Canadian federal probable effect level (PEL) guideline (CCME 2001) was used when available, otherwise the Ontario lowest effect level (LEL) guideline (Persaud *et al*. 1992) was used. Application of the SQI to Lakes Erie and Ontario was reported in Marvin *et al*. (2004). The SQI ranged from fair in Lake Ontario to excellent in eastern Lake Erie. Spatial trends in sediment quality in Lakes Erie and Ontario reflected overall trends for individual contaminant classes such as mercury and polychlorinated biphenyls (PCBs).

Environment Canada and USEPA integrated available data from the open waters of each of the Great Lakes. To date, data on lead, zinc, copper, cadmium, and mercury have been integrated. The site by site SQIs for Great Lakes sediments based on these metals are illustrated in Figure 1. The general trend in sediment quality across the Great lakes basin for the five metals is generally indicative of trends for a wide range of persistent toxics. Areas of Lakes Erie, Ontario and Michigan show the poorest sediment quality as a result of historical urban and industrial activities.

Application of the SQI has been expanded to include contaminants in streambed and riverine sediments for whole-watershed assessments. The SQI map for the Lake Erie – Lake St. Clair drainages is shown in Figure 2. Poorest sediment quality is primarily associated with Areas of Concern (AOC) where existing multi-stakeholder programs (e.g., Remedial Action Plans) are in place to address environmental impairments related to toxic chemicals.

Pressures

Management efforts to control inputs of historical contaminants have resulted in decreasing contaminant concentrations in the Great Lakes open-water sediments for the standard list of chemicals. However, additional chemicals such as brominated flame retardants (BFRs) and current-use pesticides (CUPs) may represent emerging issues and potential future stressors to the ecosystem.

The distribution of hexabromocyclododecane (HBCD) in Detroit River suspended sediments is shown in Figure 3. This compound is the primary flame retardant used in polystyrene foams, and is the third-most heavily produced BFR. Elevated levels of HBCD were associated with heavily urbanized/industrialized areas of the watershed. The HBCD distribution differs from PCBs, which are primarily associated with areas of contaminated sediment resulting from historical industrial activities including steel manufacturing and chlor-alkali production. These results corroborate observations made globally, which indicate that large urban centers act as diffuse sources of chemicals that are heavily used to support our modern societal lifestyle.

The temporal trend in the Niagara River of another class of BFRs, polybrominated diphenyl ethers (PBDEs), is shown in Figure 4. Prior to 1988, PBDEs were generally detected at low (parts per billion, ppb) concentrations, but showed a trend toward increasing concentrations over the period 1980 – 1988. After 1988, PBDE concentrations in the Niagara River showed a more rapidly increasing trend. PBDE concentrations in suspended sediments of the Niagara River are comparable to, or lower than, concentrations in sediments in other industrialized/urbanized areas of the world. The Niagara River watershed does not appear to be a significant source of PBDEs to Lake Ontario, and concentrations appear to be indicative of general contamination from a combination of local, regional, and continental sources.

Management Implications

•The Great Lakes Binational Toxics Strategy needs to be maintained to identify and track the remaining sources of contamination and to explore opportunities to accelerate their elimination.
•Targeted monitoring to identify and track down local sources of pollution should be considered for those chemicals whose distribution in the ambient environment suggests local or sub-regional sources.
•Ongoing monitoring programs in the Connecting Channels provide invaluable information on the success of binational management actions to reduce/eliminate discharges of toxics to the Great Lakes. These programs also provide important insights into pathways of new chemicals entering the Great Lakes.

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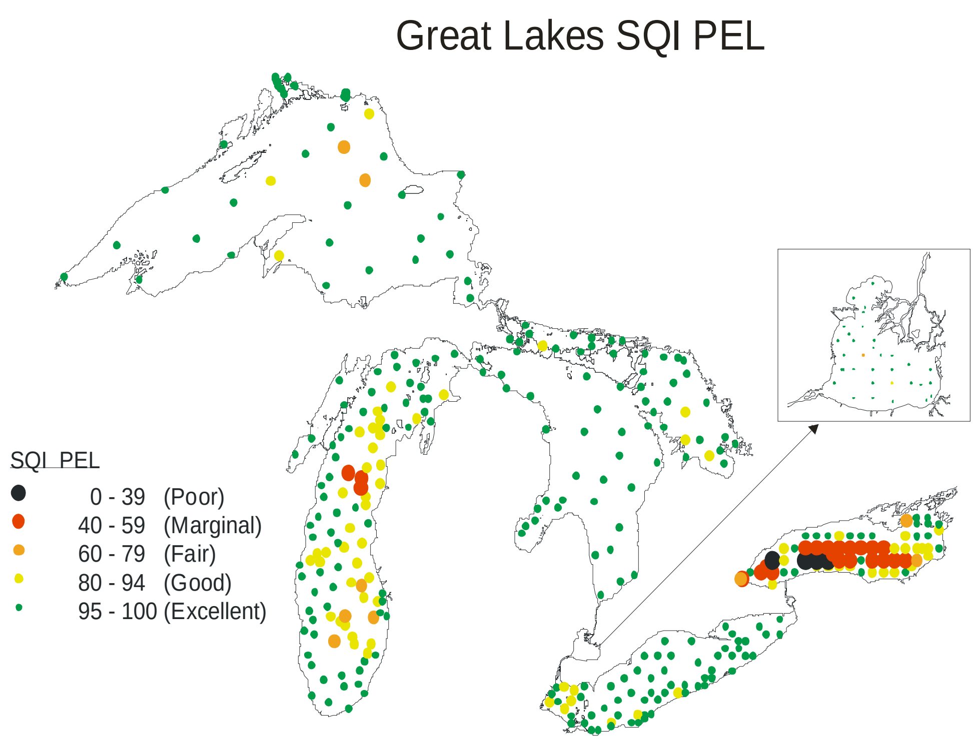

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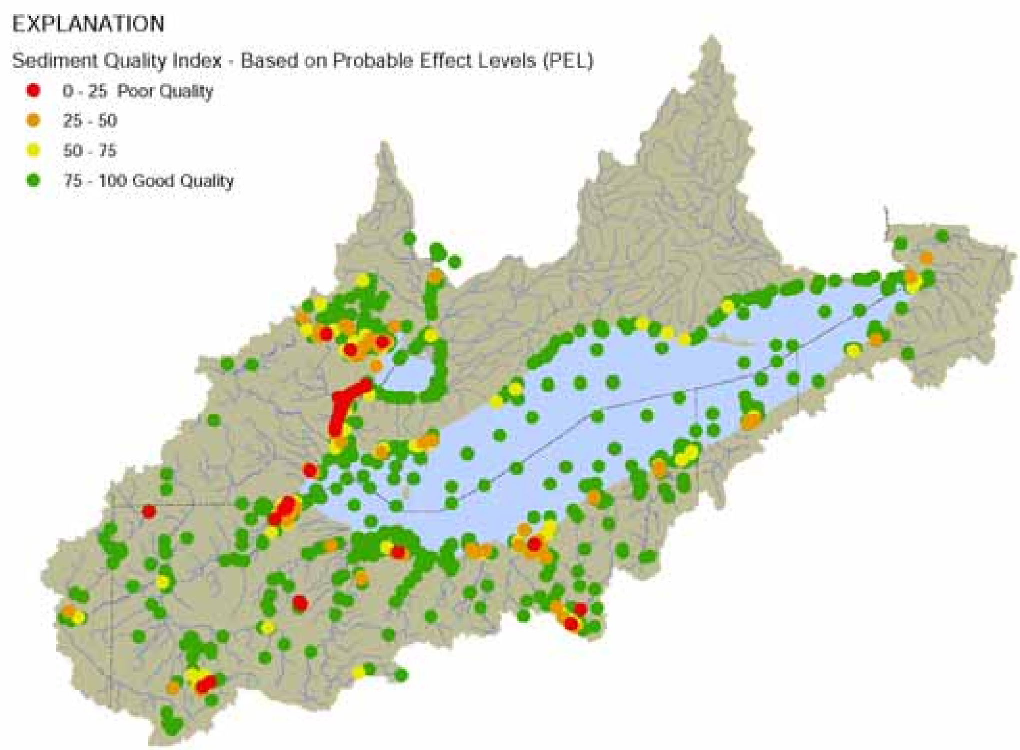

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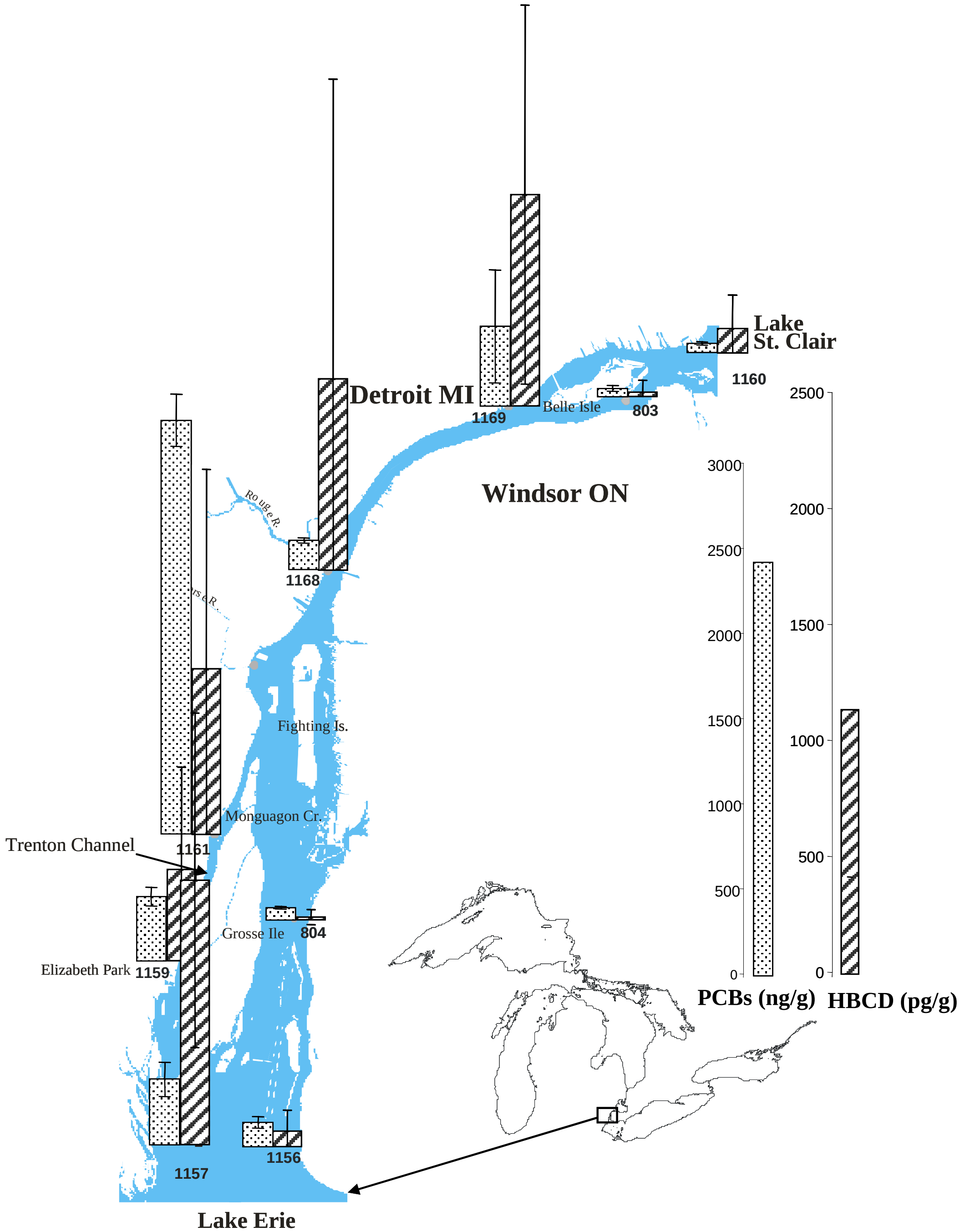

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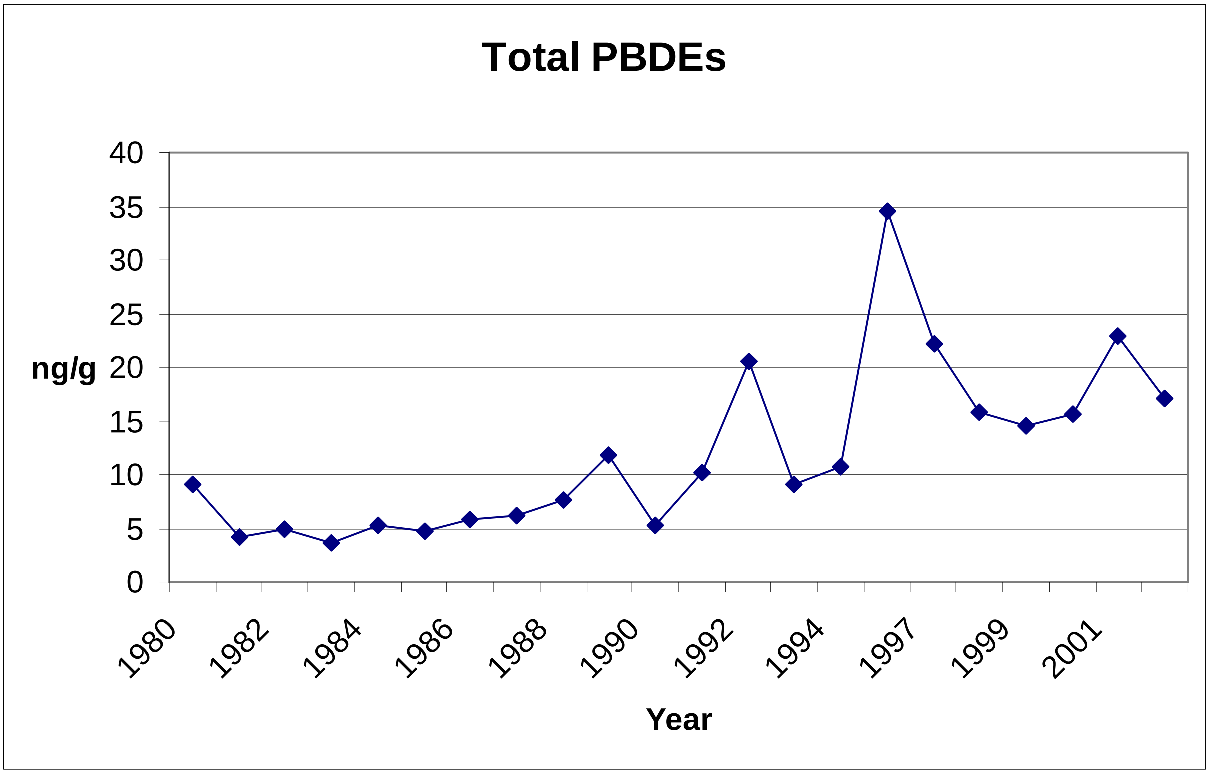

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Indicator #119

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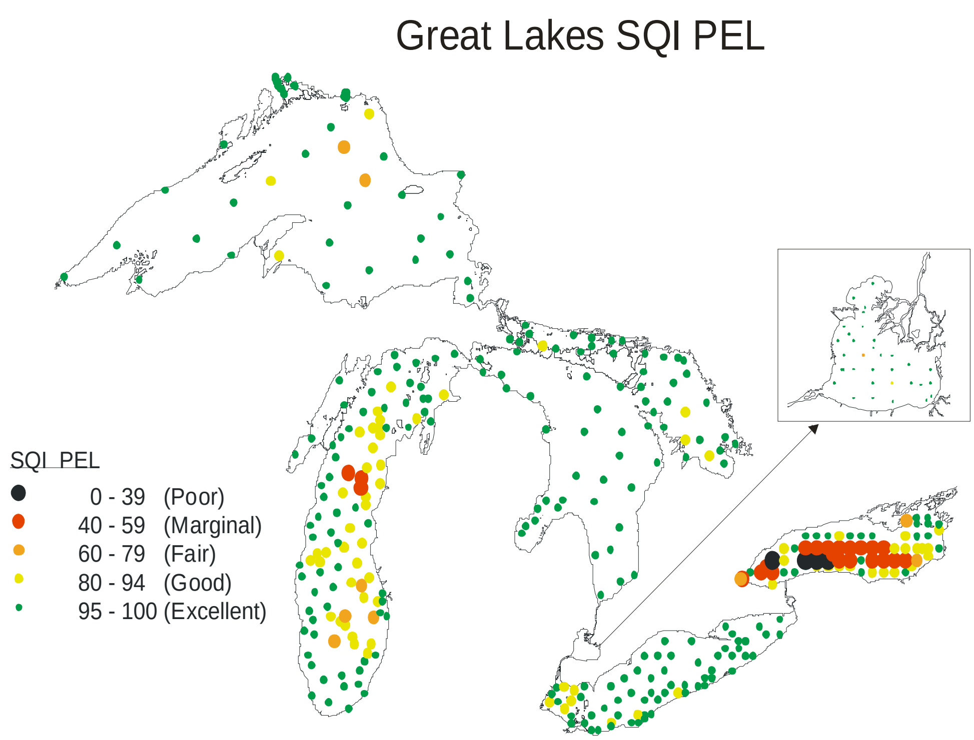
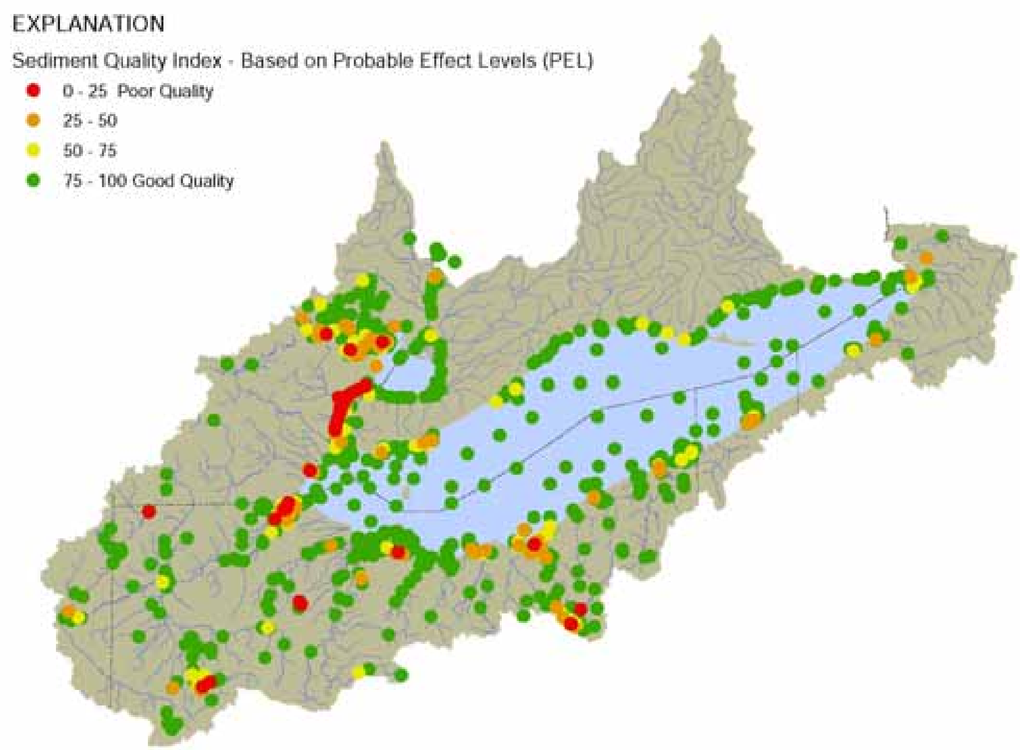


Figure 1. Site Sediment Quality Index (SQI) based on lead, zinc, copper, cadmium and mercury. Source: Chris Marvin, Environment Canada (1997-2001 data for all lakes except Michigan); and Ronald Rossmann, U.S. Environmental Protection Agency (1994-1996 data for Lake Michigan)



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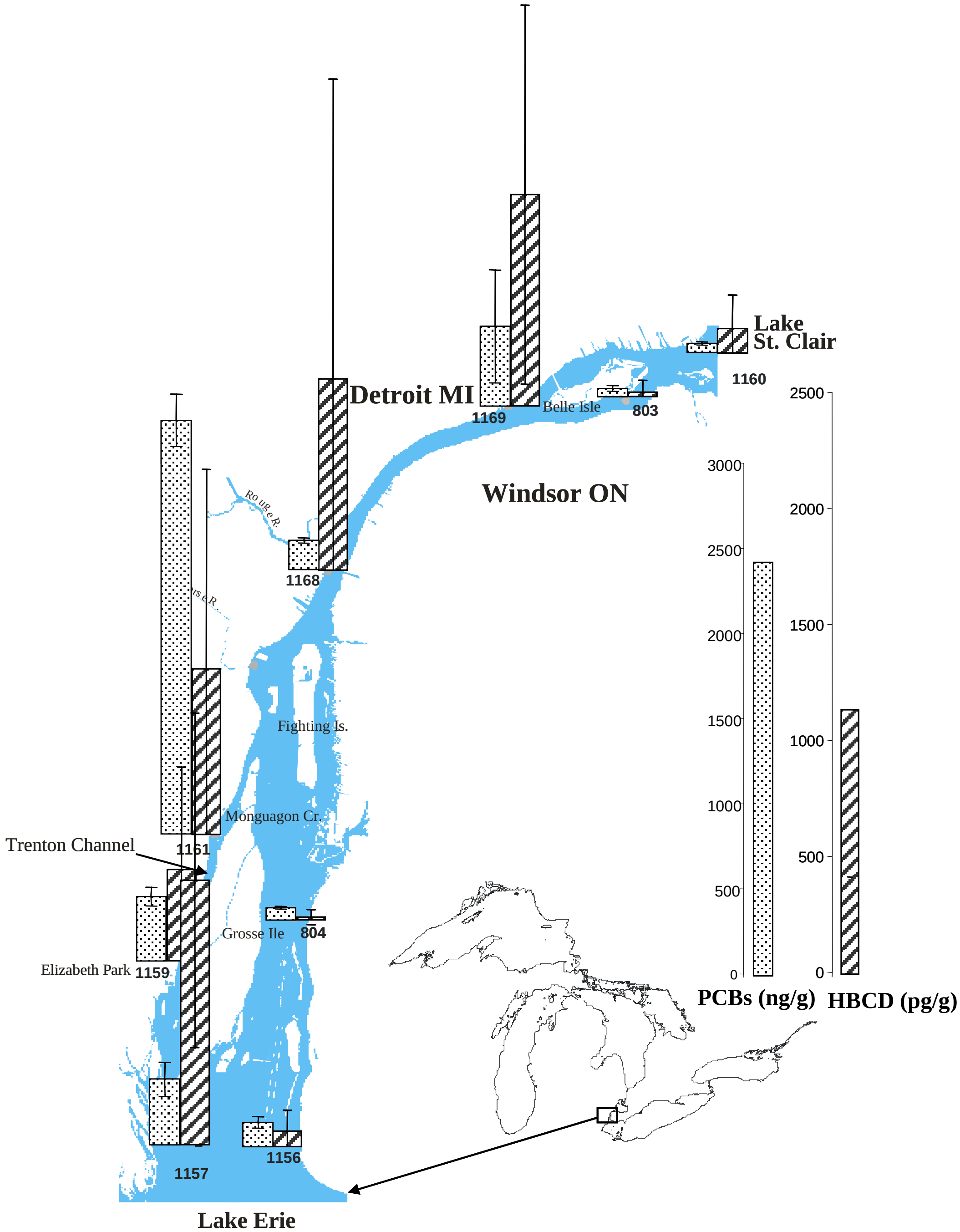
Source: Dan Button, U.S. Geological Survey



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Source: Marvin *et al*. (2006).

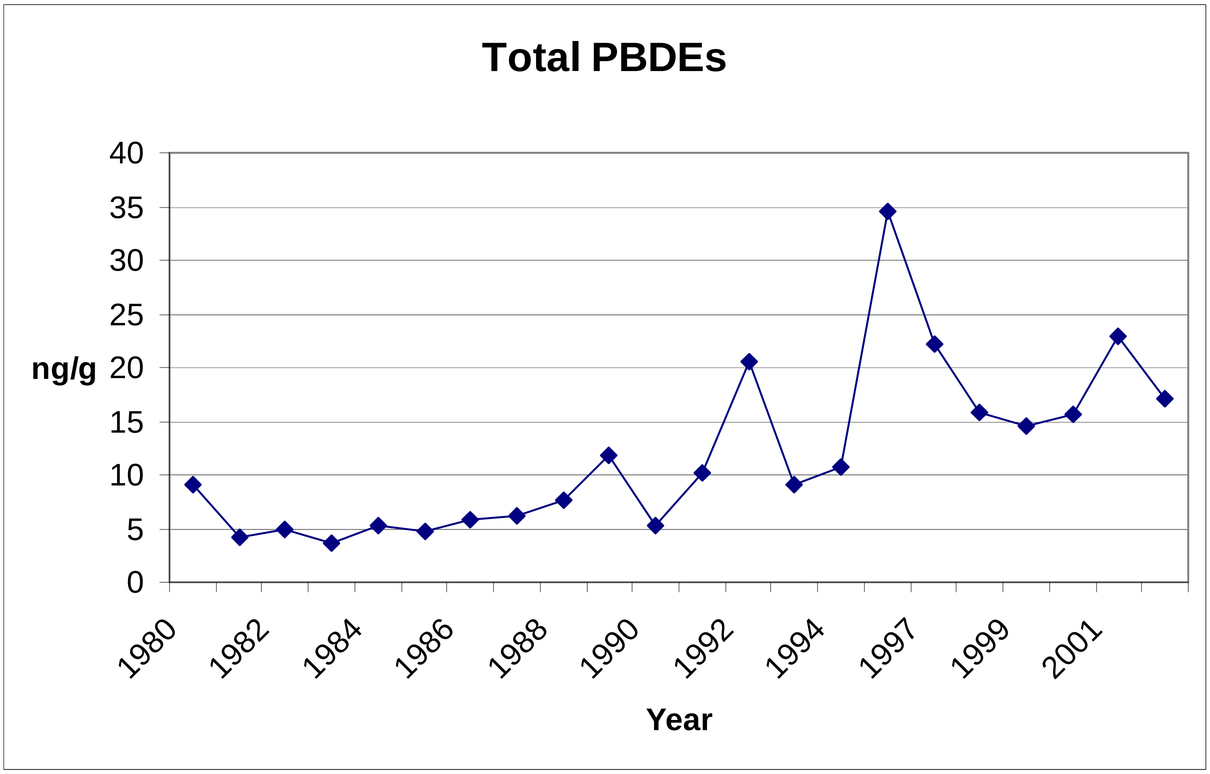

Figure 4. Temporal trend in polybrominatd diphenyl ethers (PBDEs) in Niagara River suspended sediments.
Source: Marvin *et al*. (2006).

Contaminants in Whole Fish

Indicator #121

Overall Assessment

Status: **Mixed**

Trend: **Improving**

Primary Factors Determining Status and Trend: **Whole fish are monitored by both EPA GLNPO and Environment Canada** to determine the effects of contaminant concentrations on wildlife and monitor trends. Both governments collect and analyze whole fish independently from a variety of locations within each Great Lake using different methods. The differences between the two programs, collection sites in all 5 Great Lakes, and differences in species yield a mixed status for the basin as a whole.**

**** In the spring of 2006, Environment Canada assumed the responsibilities of the Department of Fisheries and Ocean (DFO) Fish Contaminant Surveillance Program. All data included in this indicator report were produced by DFO.**

Lake-by-Lake Assessment PCB and DDT levels are measured in lake trout and walleye while only smelt samples have recent Hg trend data available.

Lake Superior

Status: Fair

Trend: Improving

Primary Factors Determining Status and Trend: Concentrations of Total PCBs show little change and Total DDT show fluctuating concentrations while mercury concentrations continue to decline. Total PCB concentrations remain above GLWQA criteria while Total DDT and mercury remain below. Contaminants in Lake Superior are typically atmospherically derived. The dynamics of Lake Superior allow for the retention of contaminants much longer than any other lake.

Lake Michigan

Status: Fair

Trend: Improving

Primary Factors Determining Status and Trend: Concentrations of Total PCBs and Total DDT are both declining. Total PCBs remain above GLWQA criteria and Total DDT remains below. Food web changes are critical to Lake Michigan contaminant concentrations, as indicated by the failure of the alewife population in the 1980's and the presence of the round goby. Aquatic invasive species, such as asian carp, are also of major concern to the lake due to the connection of Chicago Sanitary and Ship canal and the danger they pose to the food web.

Lake Huron

Status: Fair

Trend: Improving

Primary Factors Determining Status and Trend: Both Total PCBs and DDT show general declines in concentrations while mercury displays flux in concentration. Total PCB concentrations remain above GLWQA criteria while Total DDT and mercury remain below.

Contaminant loading to Saginaw Bay continues to be reflected in fish tissue.

Lake Erie

Status:	Fair
Trend:	Improving
Primary Factors Determining Status and Trend	Total PCBs and DDT show a pattern of annual concentration increases linked to changes in invasive species populations, such as zebra and guagga mussels. Aquatic invasive species are of major concern to Lake Erie because the pathways and fate of persistent toxic substances will be altered resulting in differing accumulation patterns, particularly near the top of the food chain. Mercury concentrations are the highest ever recorded in Lake Erie. Total PCB concentrations remain above GLWQA criteria while Total DDT and mercury remain below.

Lake Ontario

Status:	Fair
Trend:	Improving
Primary Factors Determining Status and Trend	Both Total PCBs and DDT show a pattern of decline while mercury concentrations show little change. Total PCB concentrations remain above GLWQA criteria while Total DDT and mercury remain below. Historic point sources of mirex and OCS in Lake Ontario have resulted in the highest concentration of these contaminants in any of the Great Lakes. The presence of contaminants of emerging concern, such as PBDEs and PFOS, continue to raise alarm in Lake Ontario, due to their continuing increases in concentration over time.

Purpose

•To describe temporal and spatial trends of bioavailable contaminants in representative open water fish species from throughout the Great Lakes;
•To infer the effectiveness of remedial actions related to the management of critical pollutants; and "To identify the nature and severity of emerging problems".

Ecosystem Objective

Great Lakes waters should be free of toxic substances that are harmful to fish and wildlife populations and the consumers of this biota. Data on status and trends of contaminant conditions, using fish as biological indicators, support the requirements of the Great Lakes Water Quality Agreement (GLWQA, United States and Canada. 1987) Annexes 1 (Specific Objectives), 2 (Remedial Action Plans and Lakewide Management Plans), 11 (Surveillance and Monitoring), and Annex 12 (Persistent Toxic Substances).

State of the Ecosystem

Background

Long-term (>25 yrs), basin-wide monitoring programs that measure whole body concentrations of contaminants in top predator fish (lake trout and/or walleye) and in forage fish (smelt) are conducted by the U.S. Environmental Protection Agency (USEPA) Great Lakes National

Program Office (GLNPO) through the Great Lakes Fish Monitoring Program and Environment Canada (EC), formerly DFO, through the Fish Contaminants Surveillance Program. Canada reports annually on contaminant burdens in similarly aged lake trout (4+ - 6+ year range), walleye (Lake Erie), and in smelt. GLNPO annually monitors contaminant burdens in similarly sized lake trout (600-700 mm total length) and walleye (Lake Erie, 400-500 mm total length) from alternating locations by year in each lake.

Chemical Concentrations in Whole Fish Great Lakes Fish:
Since the late 1970s, concentrations of historically regulated contaminants such as polychlorinated biphenyls (PCBs), dichlorodiphenyl-trichloroethane (DDT) and mercury have generally declined in most monitored fish species. The concentrations of other contaminants, both currently regulated and unregulated, have demonstrated either slowing declines or, in some cases, increases in selected fish communities. The changes are often lake-specific and relate both to the characteristics of the substances involved and the biological composition of the fish community.

The GLWQA, first signed in 1972 and renewed in 1978, expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem. When applicable, contaminant concentrations are compared to GLWQA criteria.

Σ PCBs –Total PCB concentrations in Great Lakes top predator fish have continuously declined since their phase out in the 1970s. However, rapid declines are no longer observed and concentrations in fish remain above the EPA wildlife protection value of 0.16 ppm and the GLWQA criteria of 0.1 ppm. Concentrations remain high in top predator fish due to the continued release of uncontrolled sources and their persistent and bioaccumulative nature.

Σ DDT – Total DDT concentrations in Great Lakes top predator fish have continuously declined since the chemical was banned in 1972. However, large declines are no longer observed. But rather, very small annual percent declines indicating near steady state conditions. It is important to note that the concentrations of this contaminant remain below the GLWQA criteria of 1.0 ppm. There is no EPA wildlife protection value for total DDT because the PCB value is more protective.

Mercury – Concentrations of mercury are similar across all fish in all lakes. It is assumed that concentrations of mercury in top predator fish are atmospherically driven. It is important to note that current concentrations in GLNPO top predator fish in all lakes remain above the GLWQA criteria of .5 ppm and that Canadian smelt have never been observed to be above the GLWQA criteria.

Σ Chlordane – Concentrations of total chlordane have consistently declined in whole top predator fish since the EPA banned it in 1988. Total Chlordane is composed of cis and trans-chlordane, cis and trans-nonachlor, and oxychlordane, with trans-nonachlor being the most prevalent of the compounds. While trans-nonachlor was the minor component of the total chlordane mixture, it is the least metabolized and predominates within the food web (Swackhamer, 2006).

Mirex – Concentrations of mirex are highest in Lake Ontario top predator fish due to its continued release from uncontrolled historic sources near the Niagara River.

Dieldrin – Concentrations of dieldrin in lake trout appear to be declining in all Lakes and are lowest in Lake Superior and highest in Lake Michigan. Concentrations in Lake Erie walleye were the lowest of all lakes. Aldrin is readily converted to dieldrin in the environment. For this reason, these two closely related compounds (aldrin and dieldrin) are considered together by regulatory bodies.

Toxaphene – Decreases in toxaphene concentrations have been observed throughout the Great Lakes in all media following its ban in the mid- 1980's. However, concentrations have remained the highest in Lake Superior due to its longer retention time, cold temperatures, and slow sedimentation rate. It is assumed that concentrations of toxaphene in top predator fish are atmospherically driven (Hites, 2006).

PBDEs – Both the US and Canada analyze for PBDEs in whole top predator fish. Retrospective analyses of archived samples have demonstrated the continuing increase in concentrations of polybrominated diphenyl ethers (PBDE) and are confirmed by present day concentrations in top predator fish. It is important to note that the concentration of most other persistent organic pollutants in top predator fish have declined, while PBDEs continue to increase.

Other Contaminants of Emerging Interest:
One of the most widely used BFRs is hexabromocyclododecane (HBCD). Based on its use pattern as an additive BFR, it has the potential to migrate into the environment from its application site. Recent studies have confirmed that HBCD isomers do bioaccumulate in aquatic ecosystem and do biomagnify as they move up the food chain. Recent studies by Tomy *et al*. (2004) confirmed the food web biomagnification of HBCD isomers in Lake Ontario (Table 4).

Perfluoroctanesulfonate (PFOS) has also been detected in fish throughout the Great Lakes and has also demonstrated the capacity for biomagnification in food webs. PFOS is used in surfactants such as water repellent coatings (i.e. Scotchguard ™) and fire suppressing foams. It has been identified in whole lake trout samples from all the Great Lakes at concentrations from 3 to 139 ng/g wet weight (Stock *et al*. 2003). In addition, retrospective analyses of archived lake trout samples from Lake Ontario have identified a 4.25-fold increase (43-180 ng/g wet weight, whole fish) from 1980 to 2001 (Martin *et al*., 2004).

Pressures
Current – The impact of invasive nuisance species on toxic chemical cycling in the Great Lakes is still being investigated. The number of non-native invertebrates and fish species proliferating in the Great Lakes basin continues to increase, and they continue to spread more widely. Changes imposed on the native fish communities by non-native species will subsequently alter ecosystem energy flows. As a consequence, the pathways and fate of persistent toxic substances will be altered, resulting in different accumulation patterns, particularly at the top of the food web. Each of the Great Lakes is currently experiencing changes in the structure of the aquatic community, and hence there may be periods of increases in contaminant burdens of some fish species.

A recently published, 15 year retrospective Great Lakes study showed that lake trout embryos and sac fry are very sensitive to toxicity associated with maternal exposures to 2,3,7,8-

tetrachlorodibenzo-p-dioxin (TCDD) and structurally related chemicals (Cook *et al*. 2003). The increase in contaminant load of TCDD may be responsible for declining lake trout populations in Lake Ontario. The models used in this study can be used in the other Great Lakes.

Future - Additional stressors in the future will include climate change, with the potential for regional warming to change the availability of Great Lakes critical habitats, change the productivity of some biological communities, accelerate the movement of contaminants from abiotic sources into the biological communities, and effect the composition of biological communities. Associated changes in the concentration of contaminants in the water, critical habitat availability and reproductive success of native and non-native species are also factors that will influence trends in the quantity of toxic contaminants in the Great Lakes basin ecosystem.

Management Implications

Much of the current, basin-wide, persistent toxic substance data that is reported focuses on legacy chemicals whose use has been previously restricted through various forms of legislation. There are also a variety of other potentially harmful contaminants at various locations throughout the Great Lakes that are reported in literature. A comprehensive, basin-wide assessment program is needed to monitor the presence and concentrations of these recently identified compounds in the Great Lakes basin. The existence of long-term specimen archives (>25 yrs) in both Canada and the United States could allow retrospective analyses of the samples to determine if concentrations of recently detected contaminants are changing. Further control legislation might be needed for the management of specific chemicals.

Acknowledgments

Authors: Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office;
Cameron MacEachen, Environment Canada; D. Michael Whittle, Emeritus, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Michael J. Keir, Environment Canada, and J. Fraser Gorrie, Bio-Software Environmental Data.

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Figure 2. Total PCBs levels in Odd Year whole Lake Trout (Walleye in Lake Erie), 1991 – 2003 μg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600 - 700 mm size range. Walleye = 450 - 550 mm size range. Source: U.S. Environmental Protection Agency

Figure 3. Total PCBs in 4 to 6 year old individual whole Lake Trout collected 1977 through 2005, μg/g wet weight. Source: Fisheries and Oceans Canada.

Figure 4. Total PCBs in composite rainbow smelt collected 1977 through 2005, μg/g wet weight. Source: Fisheries and Oceans Canada.

Figure 5. DDT levels in Even Year whole Lake Trout (Walleye in Lake Erie), 1972 - 2000. μg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600 - 700 mm size range. *Fish collected between 1972 and 1982 were collected at even year sites only. Walleye = 450 - 550 mm size range. Source: U.S. Environmental Protection Agency

Figure 6. DDT levels in Odd Year whole Lake Trout (Walleye in Lake Erie), 1991 - 2001. μg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600 - 700 mm size range. Walleye = 450 - 550 mm size range. Source: U.S. Environmental Protection Agency

Figure 7. Total DDT in 4 to 6 year old individual whole Lake Trout collected 1977 through 2005, μg/g wet weight. Source: Fisheries and Oceans Canada.

Figure 8. Total DDT in composite rainbow smelt collected 1977 through 2005, μg/g wet weight. Source: Fisheries and Oceans Canada.

Figure 9. Interactive GIS map of basin and web link

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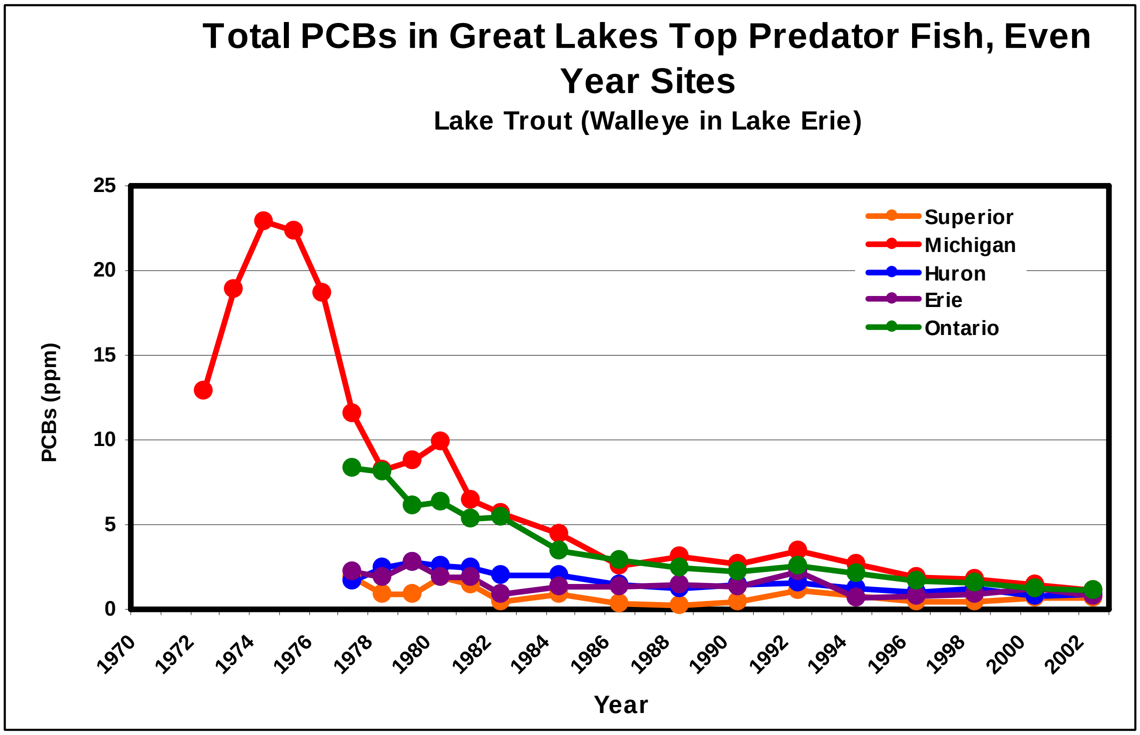

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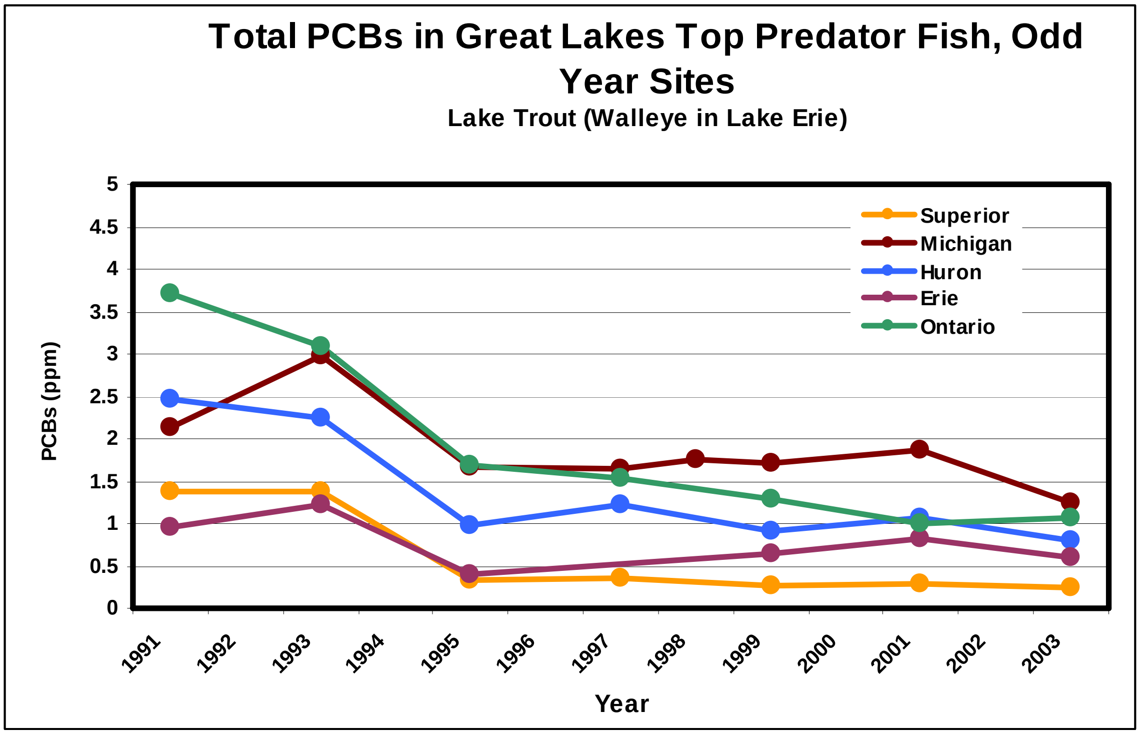

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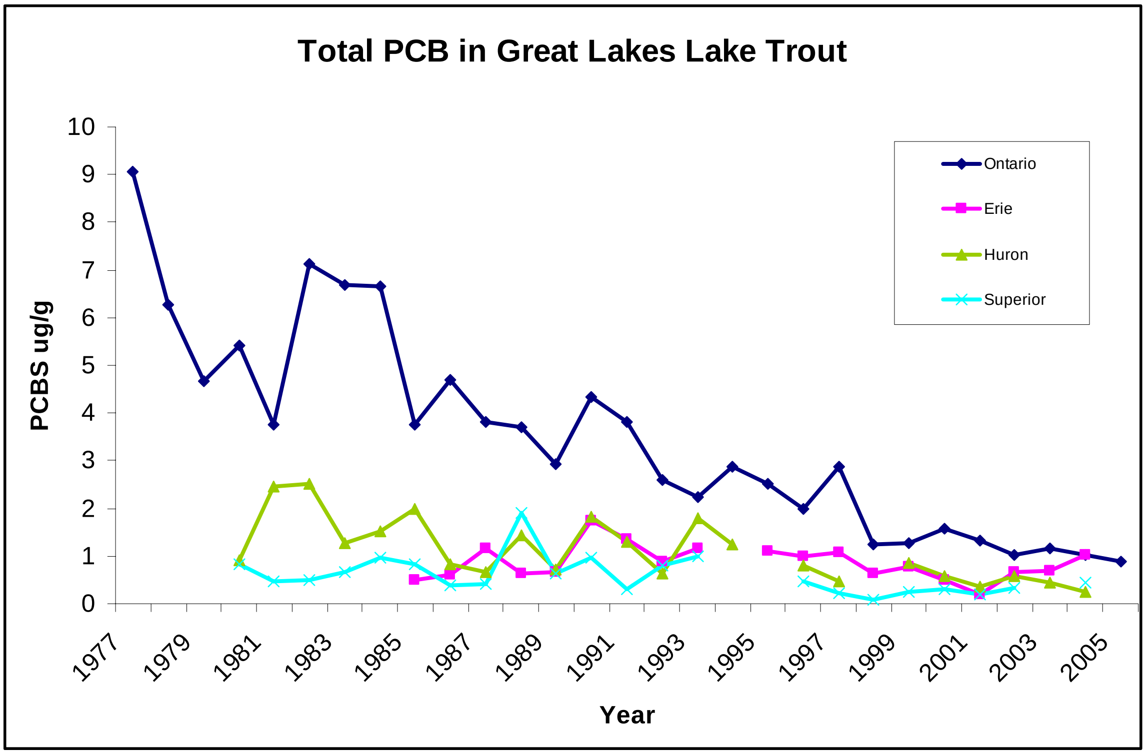

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Source: Fisheries and Oceans Canada

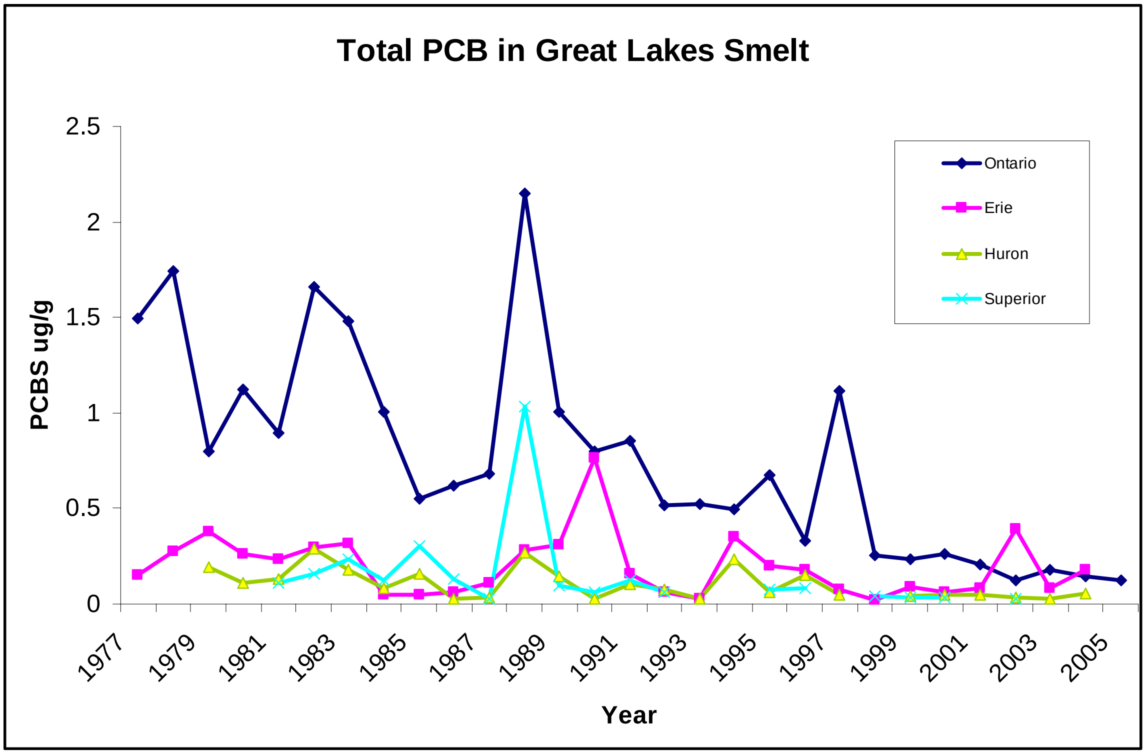
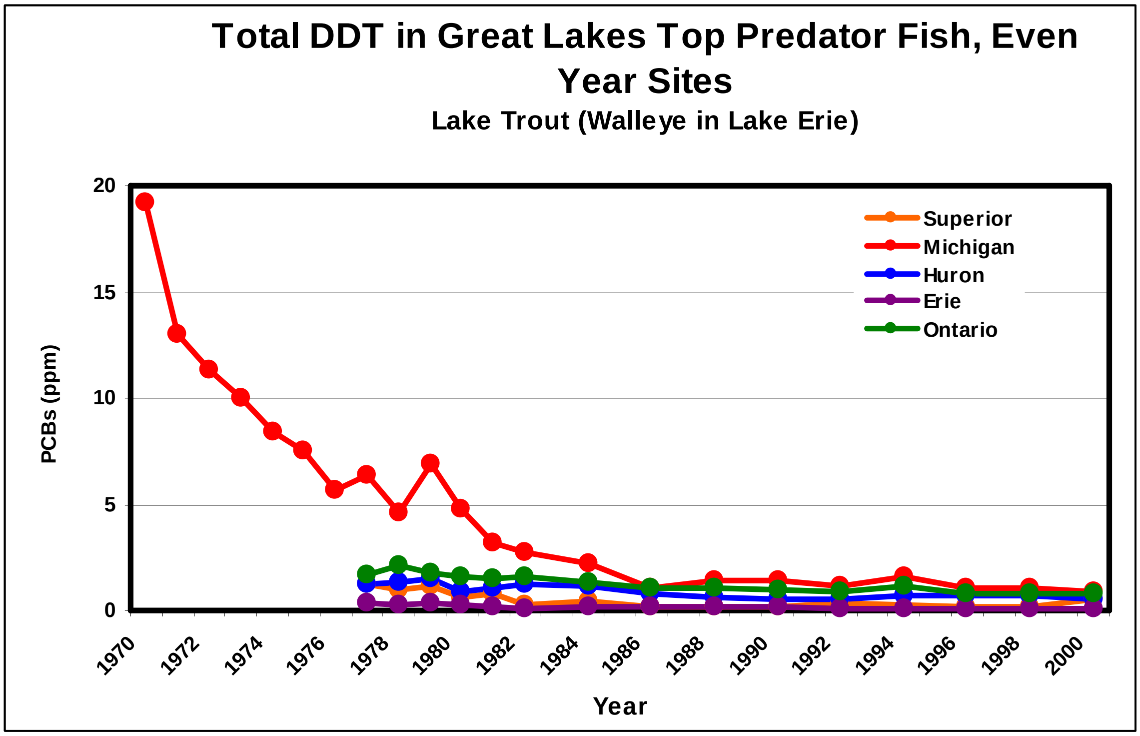


Figure 4. Total PCBs in composite rainbow smelt collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada



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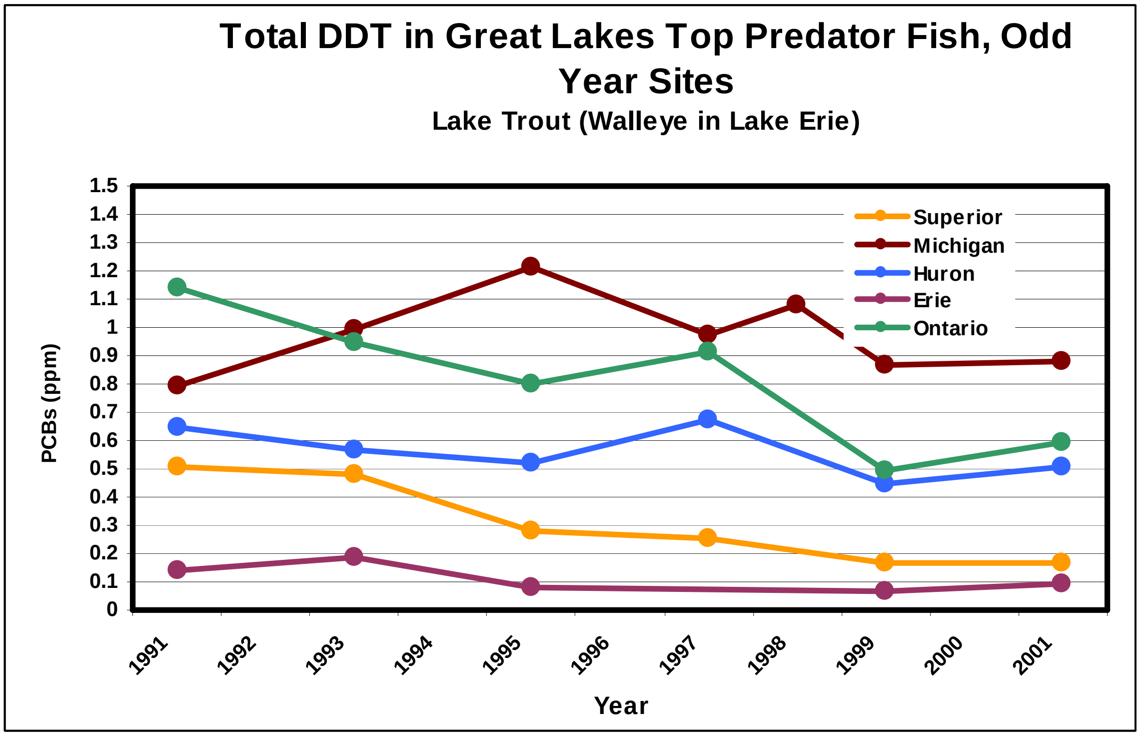
Source: U.S. Environmental Protection Agency



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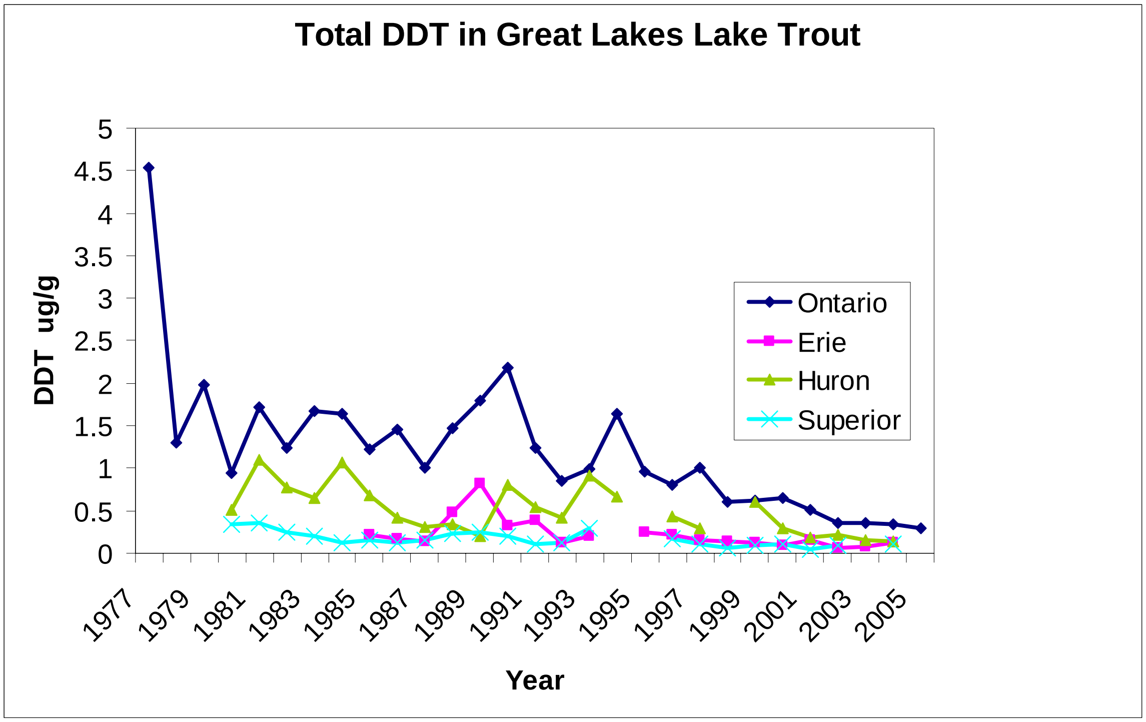

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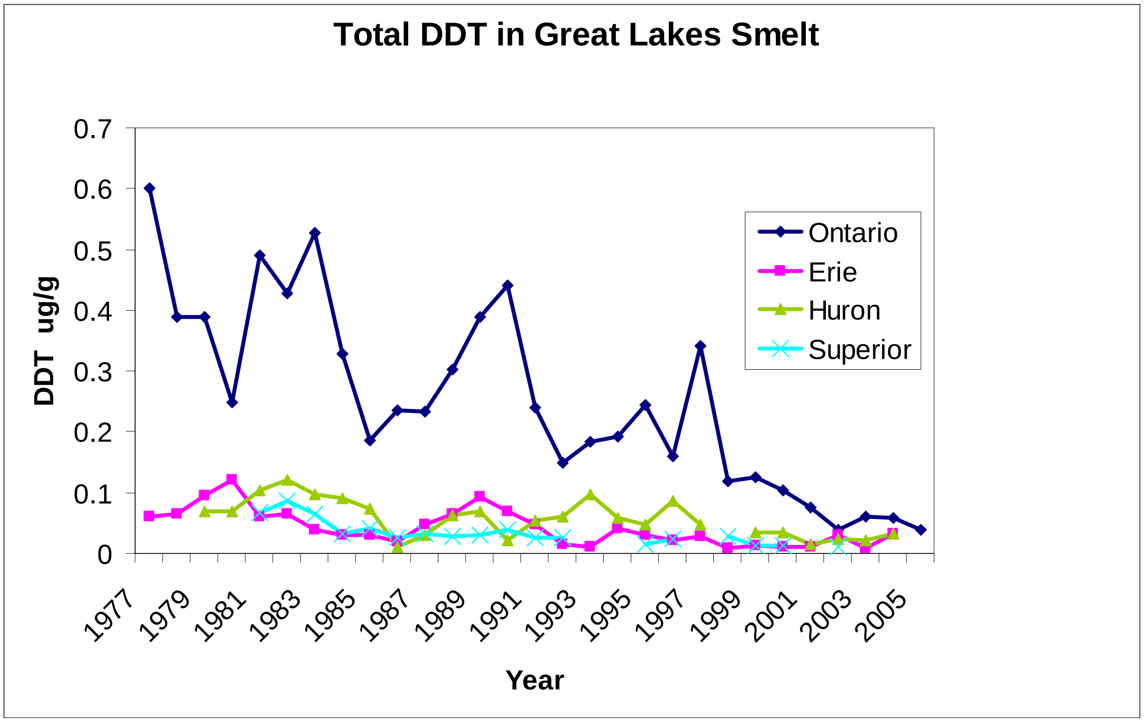

Figure 8. Total DDT in composite rainbow smelt collected 1977 through 2005, µg/g wet weight. Source: Fisheries and Oceans Canada.

Hexagenia
Indicator # 122

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Primary Factors Determining Status and Trend: **Lack of time-series and historical information. To date, only one area (western Lake Erie) has exhibited any substantial recovery of *Hexagenia* despite anecdotal reports of recovery for many areas in the Great Lakes in the mid to early 1990s. After an absence of 50 years, emerging *Hexagenia* were observed in open water of western Lake Erie in 1992 (Figure 1). Studies confirmed the return of nymphs to sediments between 1995 and 2005 (Figure 2). Between 1995 and 2005, the annual average density of nymphs was approximately 300 nymphs/m^2, a density similar to known historical abundances of nymphs in the basin. The return of this taxon may be entering the final stage of its recovery (i.e., stable annual abundances). However, large decreases in density (1997 to 1998 and 2001 to 2002, Figure 2) and poor young-of-year recruitment into the population (3 of 6 years, Figure 3) indicate that 'restoration' of nymphs has not been totally successful. The cause(s) for population decreases and failed recruitment is not known but it is suspected that it is related to residual pollution. Effects of residual pollution will likely decrease as pollution-abatement programs continue. Continued work in western Lake Erie will allow us to define a quantitative goal for successful 'restoration' of *Hexagenia* in mesotrophic waters in western Lake Erie and throughout the Great Lakes (Figure 4).**

Lake-by-Lake Assessment

Lake Superior

Status: Poor
Trend: Undetermined
Primary Factors Determining Status and Trend: Lack of time-series and historical information. Baseline (2001) information on the abundance of Hexagenia has been obtained for Duluth Harbor, Minnesota and Wisconsin (Edsall *et al*. 2004).

Lake Michigan

Status: Poor
Trend: Undetermined
Primary Factors Determining Status and Trend: Lack of time-series and historical studies. There have been no scientific conformations of anecdotal reports of *Hexagenia* except for sporadic accounts of adults near the Fox River, Green Bay, Wisconsin.

The absence of Hexagenia was confirmed in Green Bay, Wisconsin in 2001 (Edsall *et al*. 2005).

Lake Huron

Status: Poor

Trend: Undetermined

Primary Factors Determining Status and Trend: Lack of time-series and historical information. There have been no scientific conformations of anecdotal reports of *Hexagenia* adults.

The absence of *Hexagenia* was confirmed in Saginaw Bay in 2001 (Edsall *et al*. 2005).

Lake Erie

Status: Good for western Lake Erie; Mixed for the southwest shore of central Lake Erie

Trend: Improving for western Lake Erie; Mixed for southwest shore of central Lake Erie

Primary Factors Determining Status and Trend: To date, western Lake Erie is the only place where *Hexagenia* has been documented to be recovering in the Great Lakes (Krieger *et al*. 1996; Madenjian *et al*. 1998, Schloesser *et al*. 2000).
Initial signs of recovery of *Hexagenia* (i.e., evidence of adults) along the south shore of central Lake Erie (i.e., appearance and increasing distribution) occurred 1997-2000. However, since that time reports have decreased and intensive lake sampling (2001-2003) have not been able to confirm *Hexagenia* recovery.

Lake Ontario

Status: Not Assessed

Trend: Undetermined

Primary Factors Determining Status and Trend: Lack of baseline studies and historical information. There have been no scientific conformations of anecdotal reports of mayflies near Presque Isle, Pennsylvania and Bay of Quinte, Ontario.

Purpose

To assess the distribution and abundance of burrowing mayflies (*Hexagenia*) in the Great Lakes. To establish a quantitative goal for the restoration of *Hexagenia* nymphs in mesotrophic waters of the Great Lakes.

Ecosystem Objective

Historical mesotrophic habitats should be restored and maintained as balanced, stable, and productive elements of the Great Lakes ecosystem with *Hexagenia* as the key benthic invertebrate organism in the food chain. (Paraphrased from **Final Report of the Ecosystem Objectives Subcommittee**, 1990, to the IJC Great Lakes Science Advisory Board). In addition, this indicator supports Annex 2 of the GLWQA.

State of the Ecosystem
In the early 20th century, mesotrophic ecosystems in the Great Lakes had unique faunal communities that included commercially valuable fishes and associated benthic invertebrates. The primary invertebrate taxon associated with mesotrophic habitats was *Hexagenia*. *Hexagenia* was chosen by the scientific community to be a mesotrophic indicator because it is important to fishes, is relatively long lived, lives in sediments where pollution often accumulates, and is relatively sensitive to habitat changes brought on by urban and industrial pollution associated with changes as mesotrophic systems deteriorate to eutrophic systems (Schloesser and Hiltunen 1984; Schloesser 1988; Reynoldson *et al*. 1989). For example, *Hexageni*a was very abundant and important to yellow perch and walleye in the 1930s and 1940s. Then in the mid-1950s, *Hexagenia* was eliminated by low oxygen and resulting anoxic conditions created by urban and industrial pollution and growth of yellow perch declined (Beeton 1969; Burns 1985).

Initiation of pollution-abatement programs in the 1970s improved water and sediment quality in *Hexagenia* habitat throughout the Great Lakes, but the recovery of *Hexagenia* populations has been elusive (Krieger *et al*. 1996; Schloesser *et al*. 2000). Then in the early 1990s, soon after the invasion of exotic dreissenid mussels, anecdotal reports of adult *Hexagenia* (winged dun ans spinner) occurred in many bays and interconnecting rivers of the Great Lakes after absences of 30-60 years (Figure 1).

The first sign of the potential recovery of *Hexagenia* in western Lake Erie began with an anecdotal report of adult mayflies in open waters of the basin by scientists on the research vessel *Limnos* (Kreiger *et al*. 1996; Madenjian *et al*. 1998; Schloesser *et al*. 2000). Nymphs were confirmed in sediments at very low densities (ca. 9 nymphs/m^2) in 1993 and intensive studies began in 1995 (Figure 2) (Kreiger *et al*. 1996; Schloesser, unpublished data). Densities of nymphs increased between 1995 and 1997 and then decreased between 1997 and 1998. This pattern of increasing densities followed by a large decrease occurred again between 2001 and 2002. A population study of *Hexagenia* revealed that sharp declines in densities were partly attributable to failed young-of-year (YOY) recruitment (Figure 3) (Bridgeman *et al*. 2002). No YOY nymphs were found in 1997, which corresponded to the largest observed decline in *Hexagenia* density during the last decade. A similar decline occurred between 2001 and 2002 when few YOY nymphs were produced. However, a slight increase occurred between 2002 and 2003 even though relatively few YOY nymphs were recruited into the population indicating that some other factor(s) contributes to density fluctuations observed in western Lake Erie in the 1990s and 2000s.

Anecdotal reports of winged *Hexagenia* mayflies in the 1990s also included the south shore of Lake Michigan, Chicago, Illinois, the Fox River near Green Bay, Lake Michigan, Saginaw Bay near Standish, Michigan, the south shore of central Lake Erie near Sandusky, Ohio, Presque Isle of eastern Lake Erie, Pennsylvania, and the northern shore in the Bay of Quinte, eastern Lake Ontario, Picton, Ontario. To date, only the possible recovery of *Hexagenia* along the south shore of central Lake Erie has been investigated (K. Kreiger, personal communication). An initial recovery of nymphs occurred along the south shore between 1997 and 2000. However, intensive scientific surveys between 2001 and 2003 indicate that a sustained recovery of *Hexagenia* along the shore of south central Lake Erie has not occurred.

Pressures
Hexagenia are extirpated at moderate levels of pollution and may even show a graded response to the degree of pollution (Edsall *et al*. 1991; Schloesser *et al*. 1991). High *Hexagenia* abundance is strongly indicative of adequate levels of dissolved oxygen in overlying waters and uncontaminated surficial sediments. Probable causative agents of impaired *Hexagenia* populations include excess nutrients, oil, heavy metals, and various other pollutants in surficial sediments.

A portion of the general public has developed a negative perception of *en masse* swarms of adult *Hexagenia* because they can disrupt recreational use of shorelines and this perception has been incorporated into management goals for the recovery of *Hexagenia* in western Lake Erie (see Management Implications below). Such perceptions may create pressures for management to implement actions that manage lake systems below the natural carrying capacity of *Hexagenia* in mesotrophic waters of the Great Lakes.

Management Implications
Management entities in both Europe and North America desire some level of abundance of burrowing mayflies, such as *Hexagenia*, in mesotrophic habitats (Fremling and Johnson 1990; Bij de Vaate *et al*. 1992; Ohio Lake Erie Commission 1998). Recoveries of burrowing mayflies, such as *Hexagenia* spp., in rivers in Europe and North America and now in western Lake Erie clearly show how properly implemented pollution controls can bring about the recovery of large mesotrophic ecosystems. With recovery, *Hexagenia* in the Great Lakes will probably reclaim its functional status as a major trophic link between detrital energy pools and economically valuable fishes such as yellow perch and walleye.

The recovery of *Hexagenia* in western Lake Erie reminds us of an outstanding feature associated with using *Hexagenia* as an indicator of ecosystem health — the massive swarms of winged adults that are typical of healthy, productive *Hexageni*a populations. These swarms are highly visible to the public who use them to judge success of pollution-abatement programs by seeing a 'real' species that signifies the return of a 'real' habitat to a desirable condition in the Great Lakes. This public perception has influenced target values set by management for the recovery of *Hexagenia* in western Lake Erie (i.e., imperiled and good above excellent, Figure 4). However, values above excellent are based on societies' perception of excessive *en masse* emergences of winged *Hexagenia* which affect electrical power generation, vehicle traffic, and outdoor activities. These values may not represent the best scientific information for the historic/natural carrying capacity of *Hexagenia* in mesotrophic waters. For example, the target value of excellent is based on historical densities, a desire to return the system to an earlier more 'pristine' condition, and provide prey for valuable fishes. Yet, there is no scientific information that indicates densities of nymphs above 'excellent' would be in conflict with historical data, previous system conditions, and prey availability to fishes.

Comments from the author(s)
In the early 20th century, *Hexagenia* were believed to be abundant in all mesotrophic waters of the Great Lakes including Green Bay (Lake Michigan), Saginaw Bay (Lake Huron), Lake St. Clair, western Lake Erie, Bay of Quinte (Lake Ontario), and portions of interconnecting rivers and harbors. Thirty years of pollution-abatement programs may have allowed *Hexagenia* to return to

other areas of the Great Lakes besides western Lake Erie as evidenced by anecdotal sightings of winged mayflies in the 1990s. However, anecdotal reports have slowed and only one scientific study (K. Kreiger, personal communication) has been performed to confirm anecdotal reports and that study in central Lake Erie could not verify any *Hexagenia* recovery.

The only sustained recovery of *Hexagenia* in the Great Lakes (i.e., western Lake Erie) should be monitored for another 4-6 years to determine annual variability and the carrying capacity of this taxon in mesotrophic waters. If scientifically measured, the recovery will provide management agencies with a quantitative endpoint of *Hexagenia* density which can be used to measure recovery to a mesotrophic state in waters throughout the Great Lakes. In addition, a scientifically determined carrying capacity of *Hexagenia* may also be useful as a benthic indicator for remediation of contaminated sediments and as a guide for acceptable levels for food for valuable percid communities. Contaminant levels in sediments that meet USEPA and OMOE guidelines (i.e., "clean dredged sediment") and IJC criterion for oil and hydrocarbons (i.e., "sediment not polluted") will not impair *Hexagenia* populations. There will be a graded response to concentrations of metals and oil in sediment exceeding these guidelines for clean sediment. Reductions in phosphorus levels in formerly eutrophic habitats are likely to be accompanied by colonization of *Hexagenia*, if surficial sediments are otherwise uncontaminated. Since *Hexagenia* can be one of the largest and most abundant prey for percid fishes such as yellow perch and young walleye the reestablishment of *Hexagenia* in nearshore waters of Great Lakes should be encouraged.

Acknowledgments
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Source: Drawn by Martha Thierry, courtesy of the Detroit Free Press.

Figure 2. Densities (number/m^2) of *Hexagenia* obtained in three studies (colored markers) in western Lake Erie 1995-2005. Line of abundance fit by eye.
Source: Unpublished data, DWS)

Figure 3. Recruitment of young-of-year *Hexagenia* in western Lake Erie 1997-2002 Source: Schloesser and Nalepa 2001; Bridgeman *et al*. 2005.

Figure 4. Densities (number/m^2) of *Hexagenia*, three-year running average of densities, and subjective target-reference values of desired abundance (i.e., poor, fair, good, etc.) in western Lake Erie.
Source: After Ohio Lake Erie Commission 2004.

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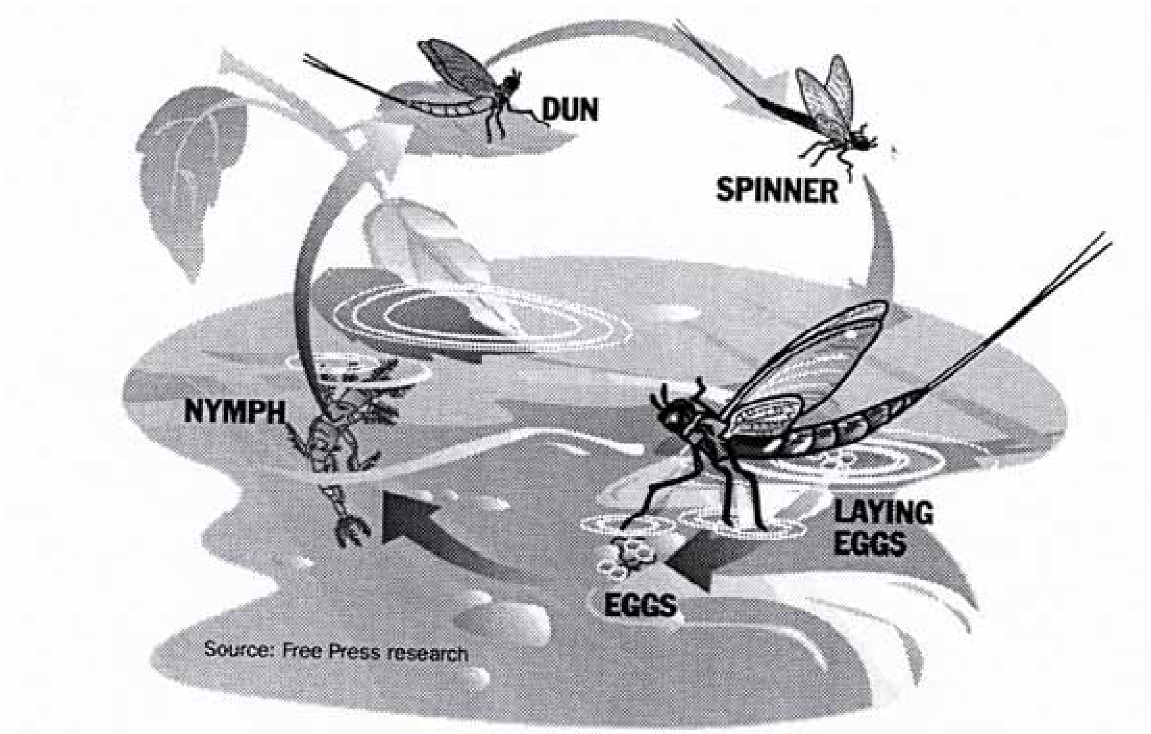

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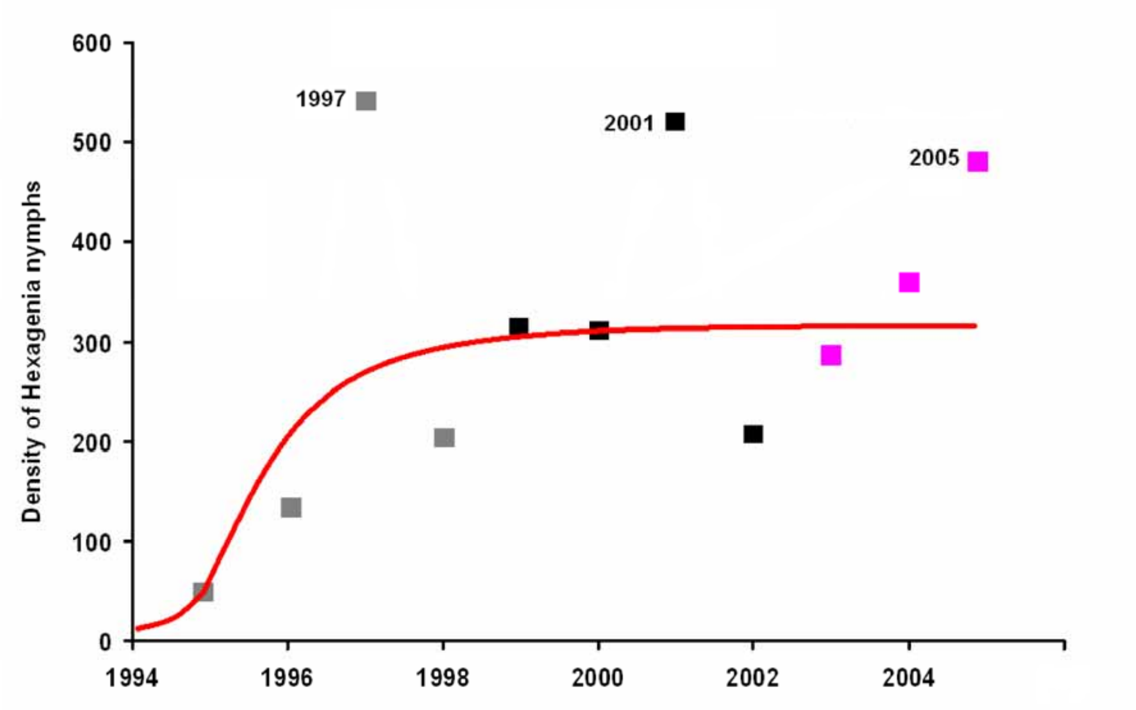

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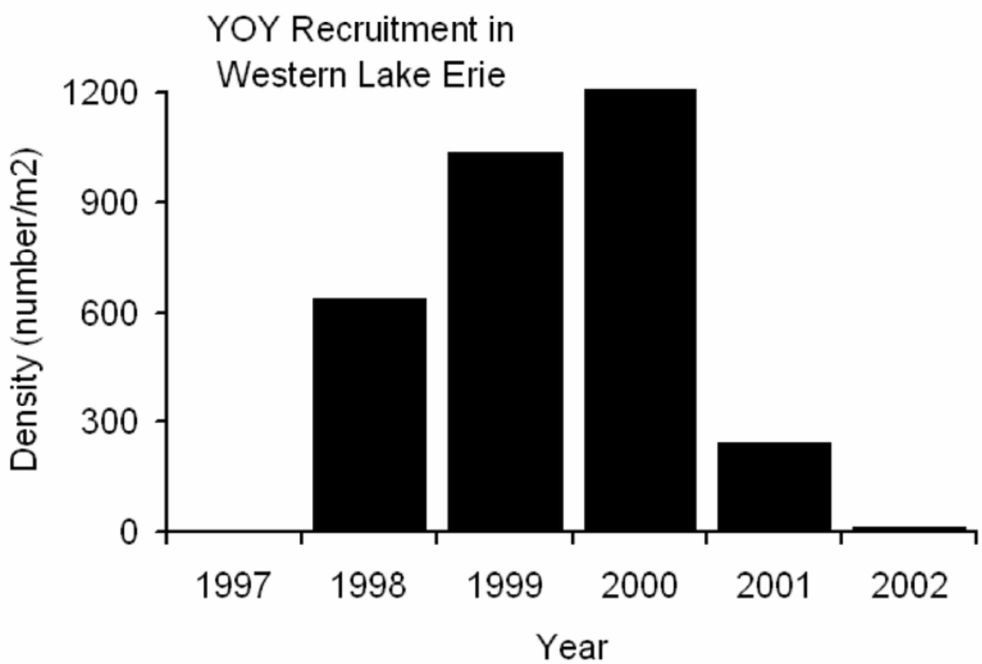

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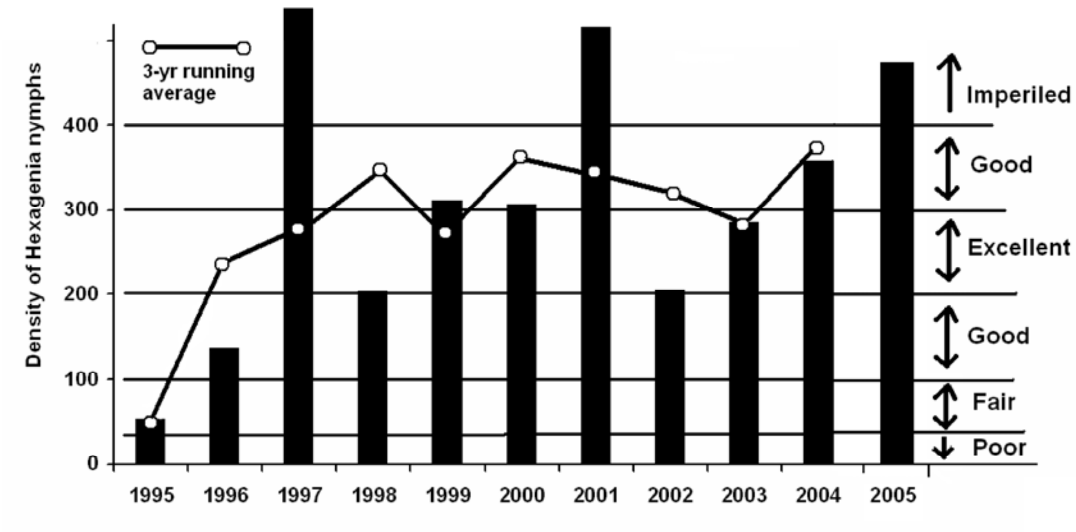

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Source: After Ohio Lake Erie Commission 2004.

Abundances of the Benthic Amphipod Diporeia spp.
Indicator #123

Overall Assessment

Status:	**Mixed**
Trend:	**Deteriorating**
Primary Factors Determining Status and Trend	**Abundances of the benthic amphipod *Diporeia* spp. continue to decline in Lakes Michigan, Huron, and Ontario. While it is presently gone or rare in shallow waters in each of these lakes, it is also declining in deeper, offshore waters. The decline in the latter regions is temporally linked to the expansion and increase of quagga mussels. Studies on trends in Lake Superior are conflicting, but the general opinion of researchers is that declines are not occurring. *Diporeia* are currently gone or very rare in Lake Erie.**

Lake-by-Lake Assessment
Lake Superior

Status:	Mixed
Trend:	Unchanging
Primary Factors Determining Status and Trend	Data sets are conflicting on current trends of *Diporeia* populations in Lake Superior. One long-term monitoring program shows that *Diporeia* abundances are declining in offshore areas (> 90 m), but abundances in nearshore areas (< 65 m) remain unchanged. Other long and short-term sampling programs show no overall trend in either offshore or nearshore areas.

Lake Michigan

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	*Diporeia* abundances continue to decline in Lake Michigan. A recent lakewide survey (in 2005) indicated abundances were lower by 84 % compared to abundances found in 2000 (Figure 1). *Diporeia* are now completely gone from depths < 80 m over most of the lake and abundances are in the state of decline at depths > 80 m.

Lake Huron

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	*Diporeia* abundances continue to decline in Lake Huron. The most recent lakewide survey in the main basin (in 2003) indicated abundances were lower by 57 % compared to abundances found in 2000. *Diporeia* are now completely gone from depths < 60 m except in the northeastern end and continue to decline at depths > 60 m. Annual monitoring at 11 sites indicated that, in 2005, *Diporeia* were gone from 5 sites and abundances were lower compared to 2004 at the other 6 sites. Because of insufficient data, trends in Georgian Bay and North Channel are not known. However, limited temporal and spatial data from the southern end of Georgian Bay showed that *Diporeia* have been declining since 2000 and are now completely gone at depths < 93 m.

Lake Erie

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Because of shallow, warm waters, *Diporeia* are naturally not present in the western and central basins. *Diporeia* declined in the eastern basin beginning in the early 1990s and have not been found since 1998.

Lake Ontario

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Based on several limited surveys in 2005, *Diporeia* continue to decline in Lake Ontario. In one survey of 11 sites, Diporeia declined at 2 sites and increased slightly at 2 sites compared to 2004. It was not found at 6 sites in both years. In another survey of 14 sites, *Diporeia* declined at sites < 140 m, but abundances increased slightly at sites > 190 m. It was not found at sites < 90 m over most of the lake.

Purpose

To provide a measure of the biological integrity of the offshore regions of the Great Lakes by assessing the abundance of the benthic macroinvertebrate *Diporeia*.

Ecosystem Objective

The ecosystem goal is to maintain a healthy, stable population of *Diporeia* in offshore regions of the main basins of the Great Lakes, and to maintain at least a presence in nearshore regions.

State of the Ecosystem

Background

This glacial-marine relic was once the most abundant benthic organism in cold, offshore regions (> 30 m) of each of the lakes. It was present, but less abundant in nearshore regions of the open lake basins, but naturally absent from shallow, warm bays, basins, and river mouths. *Diporeia* occurs in the upper few centimetres of bottom sediment and feeds on algal material that freshly settles to the bottom from the water column (i.e., mostly diatoms). In turn, it is fed upon by most species of fish, in particular by many forage fish species which serve as prey for the larger piscivores such as trout and salmon. For example, sculpin feed almost exclusively upon *Diporeia*, and sculpin are fed upon by lake trout. Also, lake whitefish, an important commercial species, feeds heavily on *Diporeia*. Thus, *Diporeia* was an important pathway by which energy was cycled through the ecosystem, and a key component in the food web of offshore regions. The importance of this organism is recognized in the Great Lakes Water Quality Agreement (Supplement to Annex 1 – Specific Objectives).

On a broad scale, abundances are directly related to the amount of food settling to the bottom, and population trends reflect the overall productivity of the ecosystem. Abundances can also vary somewhat relative to shifts in predation pressure from changing fish populations. In nearshore regions, this species is sensitive to local sources of pollution.

Status of *Diporeia*
Diporeia populations are currently in the state of dramatic decline in Lakes Michigan, Ontario, and Huron, and are completely gone or very rare in Lake Erie. Results are conflicting for Lake Superior. One data set shows a trend of declining abundances in offshore waters, but other data sets show no trend. In all the lakes except Superior, abundances have decreased progressively from shallow to deeper areas. Initial declines were first observed in all lake areas within 2-3 years of when zebra mussels (*Dreissena polymorpha*) or quagga mussel (*Dreissena bugensis*) first became established. These two species were introduced into the Great Lakes in the late 1980s via the ballast water of ocean-going ships. Reasons for the negative response of *Diporeia* to these mussel species are not entirely clear. One hypothesis is that dreissenid mussels are out competing *Diporeia* for available food. That is, large mussel populations were filtering food material before it reached the bottom, thereby decreasing amounts available to *Diporeia*. However, evidence suggests that the reason for the decline is more complex than a simple decline in food because *Diporeia* have completely disappeared from areas where food is still settling to the bottom and where there are no local populations of mussels. Also, individual *Diporeia* show no signs of starvation before or during population declines. Further, *Diporeia* and *Dreissena* apparently coexist in some lakes outside of the Great Lakes (i. e., Finger Lakes in New York).

Pressures
As populations of dreissenid mussels continue to expand, it may be expected that declines in *Diporeia* will become more extensive. In the open waters of Lakes Michigan, Huron, and Ontario, zebra mussels are most abundant at depths less than 50 m, and *Diporeia* are now gone or rare from lake areas as deep as 90 m. Recently, quagga mussel populations have increased dramatically in each of these lakes and are occurring at deeper depths than zebra mussels. The decline of *Diporeia* at depths > 90 m can be attributed to the expansion of quagga mussels to these depths.

Management Implications
The continuing decline of *Diporeia* has strong implications to the Great Lakes food web. As noted, many fish species rely on *Diporeia* as a major prey item, and the loss of *Diporeia* will likely have an impact on these species. Responses may include changes in diet, movement to areas with more food, or a reduction in weight or energy content. Implications to populations include changes in distribution, abundance, growth, recruitment, and condition. Recent evidence

suggests that fish are already being affected. For instance, growth and condition of an important commercial species, lake whitefish, has declined significantly in areas where *Diporeia* abundances are low in Lakes Michigan, Huron, and Ontario. Also, studies show that other species such as alewife, slimy sculpin, and bloater have been affected. Management agencies must know the extent and implications of these changes when assessing the current state and future trends of the fishery. Any proposed rehabilitation of native fish species, such as the re-introduction of deepwater ciscoes in Lake Ontario, requires knowledge that adequate food, especially *Diporeia*, is present.

Comments from the author(s)

Because of the rapid rate at which *Diporeia* populations are declining and their significance to the food web, agencies committed to documenting trends should report data in a timely manner. The population decline has a defined natural pattern, and studies of food web impacts should be spatially well coordinated. Also, studies to define the cause of the negative response of *Diporeia* to *Dreissena* should continue and build upon existing information. With an understanding of exactly why *Diporeia* populations are declining, we may better predict what additional areas of the lakes are at risk. Also, by better understanding the cause, we may better assess the potential for population recovery if and when dreissenid populations stabilize or decline.

Acknowledgments

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R. Dermott, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, ON.

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Figure 1. Distribution and abundance (number per square meter) of the amphipod *Diporeia* spp. in Lake Michigan in 1994-1995, 2000, and 2005. Small crosses indicate location of sampling stations.
Source: National Oceanic & Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory

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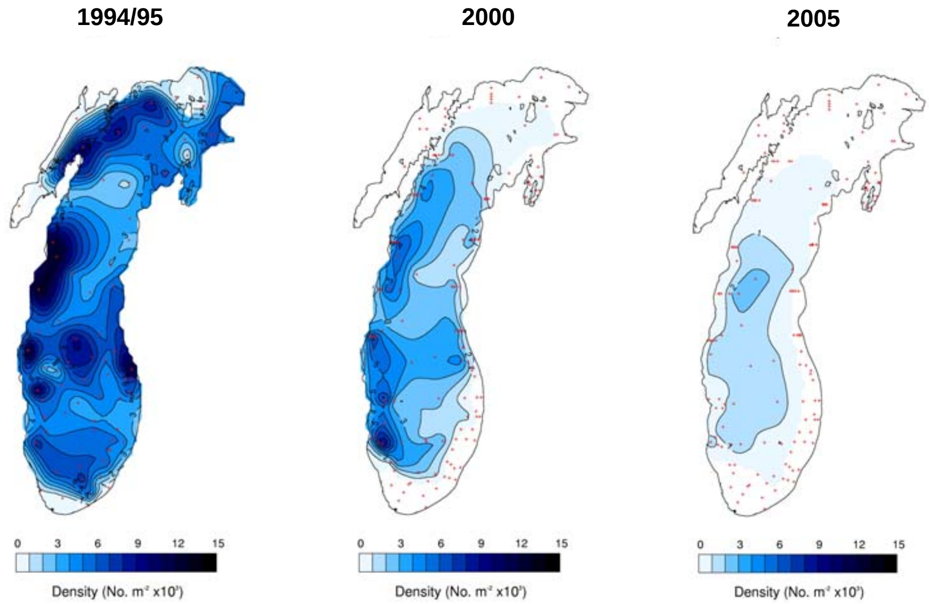

Figure 1. Distribution and abundance (No. m^{-2}) of the amphipod *Diporeia* spp. in Lake Michigan in 1994/1995, 2000, and 2005. Small crosses indicate location of sampling stations.

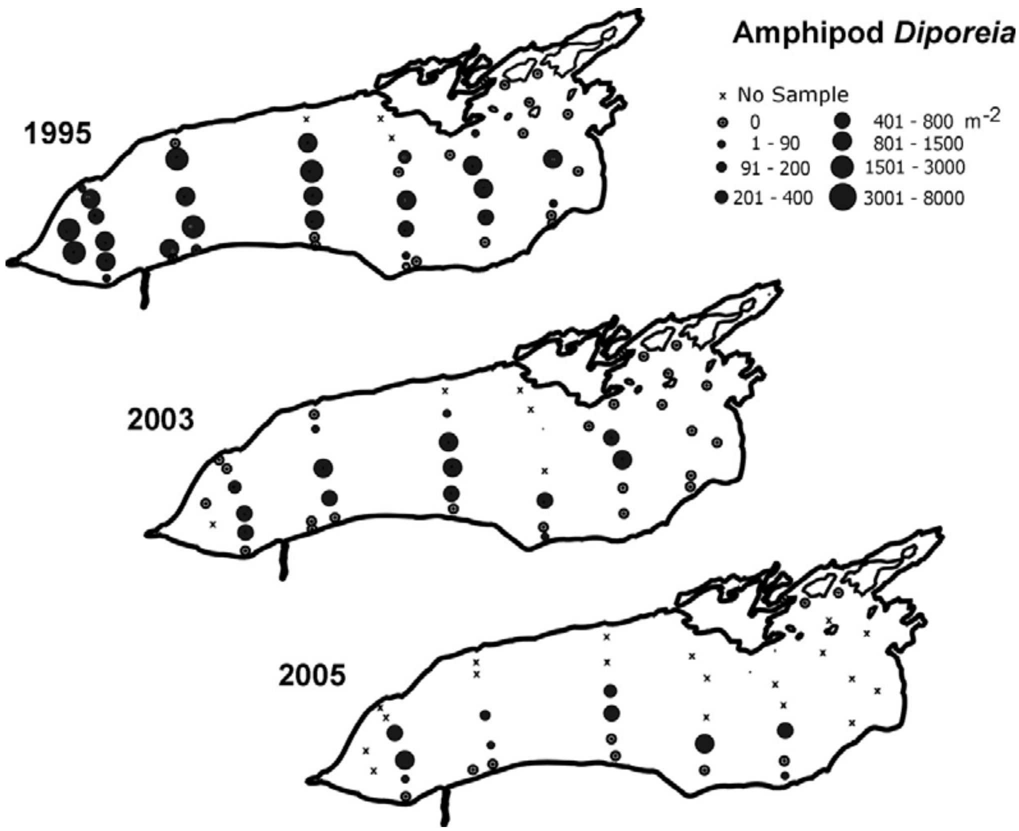

Figure 2. Distribution and abundance (No. m^{-2}) of the amphipod *Diporeia* spp. in Lake Ontario in 1995, 2003, and 2005. Small crosses indicate a site where no sample was taken.

External Anomaly Prevalence Index for Nearshore Fish
Indicator #124

Overall Assessment

Status: **Poor**
Trend: **Unchanging**
Primary Factors Determining Status and Trend

Lake-by-Lake Assessment

Lake Superior

Status: Not Assessed
Trend: Undetermined

Lake Michigan

Status: Not Assessed
Trend: Undetermined

Lake Huron

Status: Not Assessed
Trend: Undetermined

Lake Erie

Status: Poor
Trend: Unchanging

Lake Ontario

Status: Poor
Trend: Unchanging

Purpose

1) To assess select external anomalies in nearshore fish;
2) To identify nearshore areas that have populations of benthic fish exposed to contaminated - sediments; and
3) To help assess the recovery of Areas of Concern (AOCs) following remedial activities
Insert Purpose text

Ecosystem Objective

The objective is to help restoration and protection of beneficial uses in Areas of Concern or in open Great Lakes waters, including beneficial use (iv) *Fish tumors or other deformities* (Great Lakes Water Quality Agreement (GLWQA), Annex 2). This indicator also supports Annex 12 of the GLWQA.

State of the Ecosystem
Background

The presence of contaminated sediments at AOCs has been correlated with an increased incidence of external and internal anomalies in benthic fish species (brown bullhead and white suckers) that may be associated with specific groups of chemicals. Elevated incidence of liver tumors (histopathologically verified pre-neoplastic or neoplastic growths) were frequently identified during the past two decades. These elevated frequencies of liver tumours have been shown to be useful indicators of beneficial use impairment of Great Lakes aquatic habitat. External raised growths (histopathologically verified tumors on the body and lips), such as lip papillomas, have also been useful indicators. Raised growths may not have a single etiology; but, they have been produced experimentally by direct application of polynuclear aromatic hydrocarbons (PAH) carcinogens to brown bullhead skin. Field and laboratory studies have correlated verified liver and external raised growths with chemical contaminants found in sediments at some AOCs in Lake Erie, Lake Michigan, Lake Ontario and Lake Huron. Other external anomalies may also be used to assess beneficial use impairment. The external anomaly prevalence index (EAPI) will provide a tool for following trends in fish population health that can be used by resource managers and community-based monitoring programs.

The EAPI has been developed for mature (> 3 years of age) fish as a marker of both contaminant exposure and of internal pathology. Brown bullhead have been used to develop the index. They are the most frequently used benthic indicator species in the southern Great Lakes and have been recommended by the International Joint Commission (IJC) as a key indicator species (IJC 1989). The most common external anomalies found in brown bullhead over the last twenty years from Lake Erie are: 1) abnormal barbels (BA); 2) focal discoloration (FD); and 3) raised growths (RG) - on the body and lips (Figure1). Initial statistical analysis of sediments and external anomalies at different locations indicates that variations in the chemical mixtures (Total, priority and carcinogenic PAHs; DDT metabolites; organochlorine chemicals (OC); and total metals) show a statistically significant relation with a differing prevalence of individual external anomalies (raised growths and barbell abnormalities). Age and external anomalies indicate a positive correlation (Figure 2). Impairment determinations should be based on age comparisons of the prevalence of external anomalies at contaminated sites with the prevalence at “reference” (least impacted) sites (Figure 3). Preliminary data indicate that if the prevalence of raised growths on the body and lip combined is > 5%, barbell abnormalities >10% and focal discoloration (melanistic alterations) > 5% in brown bullhead, the population should be considered impaired.

Surveys conducted in 1999 and 2000 in the Detroit, Ottawa, Black, Cuyahoga, Ashtabula, Buffalo, and Niagara Rivers and at Old Woman Creek in Lake Erie demonstrated that external raised growths are positively associated with both PAH metabolites in bile and in PAH concentrations in sediment. The association with PAH metabolites in bile (Figure 4) is stronger than that with total PAH concentrations in sediments (Figure 5). Bile metabolite concentrations may be a better estimate of potential exposure of PAHs to individual fish than concentrations in sediments. The EAPI indicates the impacts from the exposure to individual fish from the PAHs as well as other compounds in the mixtures of compounds that may be present in sediments. Barbel deformities (Figure 5) also showed a positive correlation with total PAH levels in sediment. In addition to the locations listed above, the Huron River and Presque Isle Bay sites all showed a statistically significant correlation between external raised growths and concentration of heavy metals in sediment (Figure 6).

Pressures
Many Great Lakes AOCs and their tributaries remain in a degraded condition. Exposure of the fish populations to contaminated sediment continues and the elevated evidence of external anomalies still persist. The human population in the Great Lakes is expected to increase and urbanization along Great Lakes tributaries and shorelines will likely expand in the future. Therefore, some locations impacted by land use changes may continue to deteriorate even as control and remediation actions improve conditions at the older contaminated sites. As recommended for delisting, listed AOCs continue the gain knowledge in order to achieve a low EAPI to help the delisting process of the BUI for fish tumors and other deformities. A single common data base must be implemented for international brown bullhead data sets to evaluate AOC and reference conditions in each of the Great Lakes.

Management Implications
The EAPI provides managers and researchers with a tool to monitor contaminant impacts to the fish populations in Great Lakes AOCs. Additional remediation to clean up contaminated sediments at Great Lakes AOCs will help to reduce rates of external anomalies. The EAPI, particularly for brown bullheads and white suckers and the inclusion of a single common data base will help environmental managers to follow trends in fish population health and to determine the status of AOCs that may be considered for delisting (IJC Delisting Criteria, see IJC 1996).

Comments from the author(s)
This external anomaly index for benthic species has potential for defining habitats that may or may not be impacted from contaminants. Collaborative U.S. and Canadian studies investigating the etiology and prevalence of external anomalies in benthic fishes over a gradient of polluted to pristine Great Lakes habitats are desperately needed. These studies would create a common index that could be used as an indicator of ecosystem health. The establishment of single data base to house all lake wide data for each Great Lake is necessary to enable managers and decision makers to gain an understanding of the health of individual fish (e.g. brown bullhead) and their populations. Unless this takes place, understanding of health conditions at AOCs compared to the least impacted (reference) sites will remain unknown and the delisting process will not advance.

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*Dedicated to our friend and collogue Scott Brown, whose untimely passing has saddened all who knew him.

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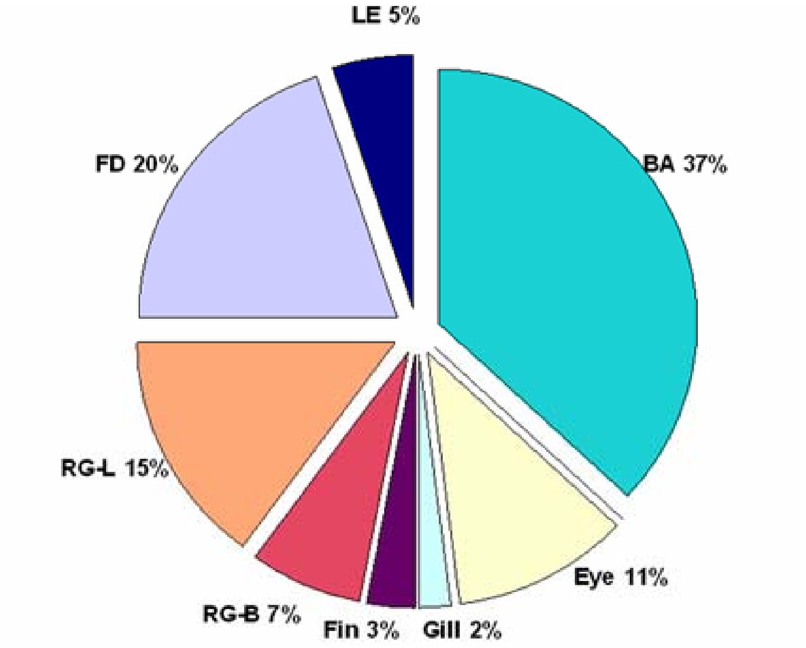

Figure 1. External Anomalies on brown bullhead collected from Lake Erie from the 1980's through 2000. BA- barbel abnormalities, RG- raised growth (body and lip), FD-focal discoloration, LE-lesion (total ca. 2400 fish).
Source: Great Lakes Science Center, Ann Arbor, MI.

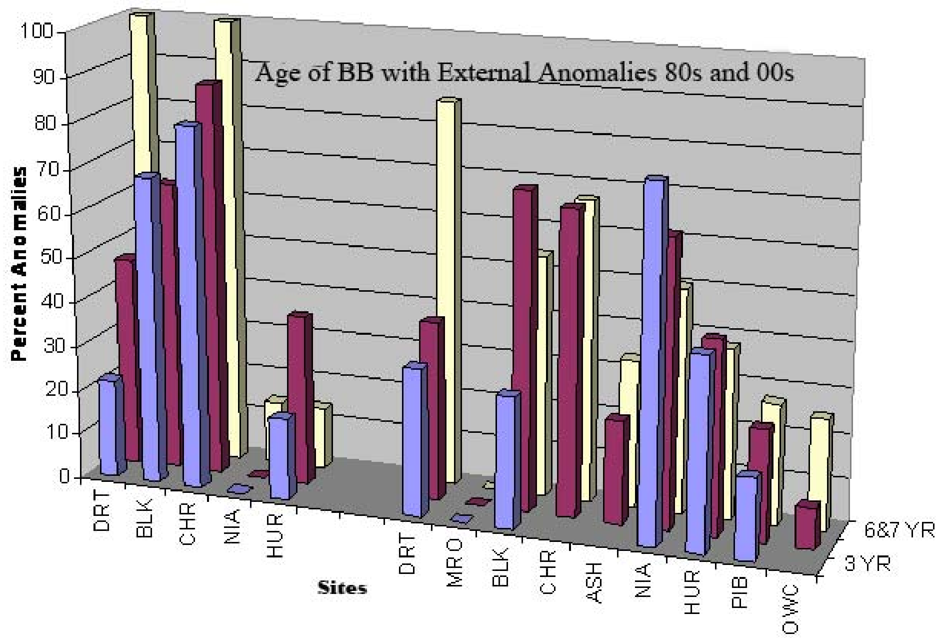

Figure 2. Age of brown bullhead at Lake Erie sites from 1986-87 and 1998-2000 collections in relation to combined external anomalies. Age groups; age 3, ages 4&5, ages 6&7.
Source: S.B. Smith, unpublished data.

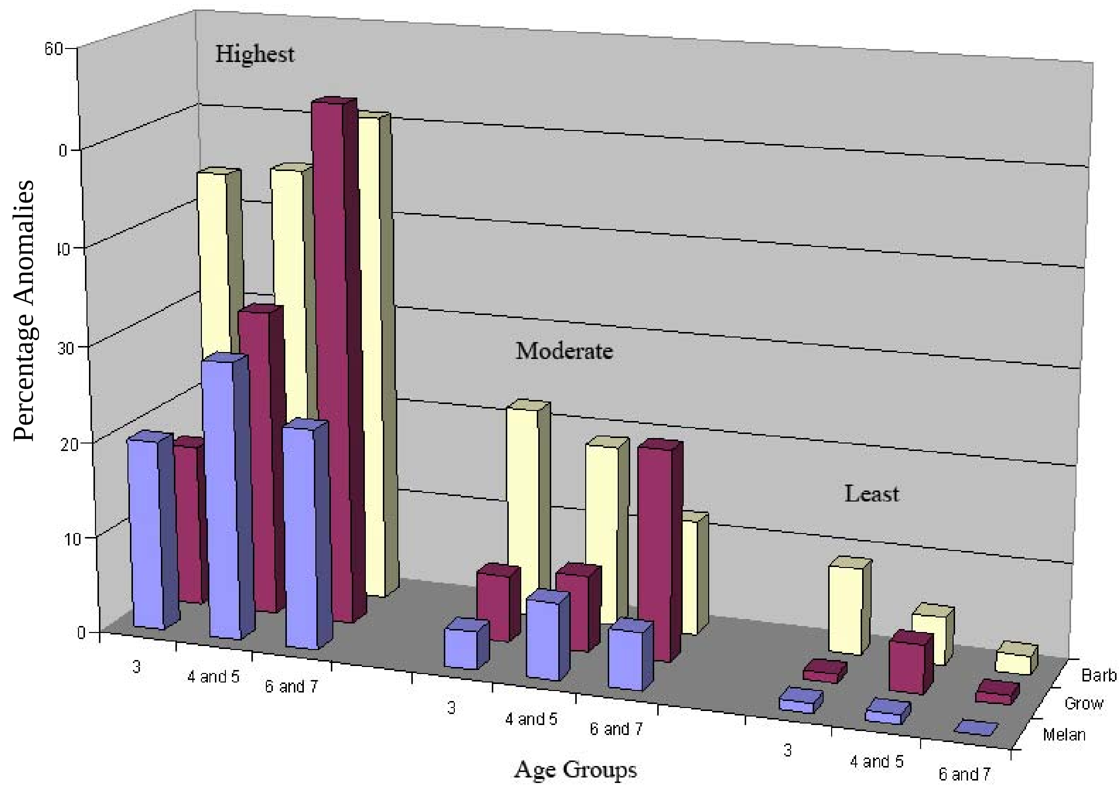

Figure 3. External anomalies (Melanoma, Raised Growth on body and lips, and Barbell abnormalities) in relation to sites classified for sediment contaminants and BB morphology from all collections in the 1980's and 1990's.
Source: S. B. Smith, unpublished data.

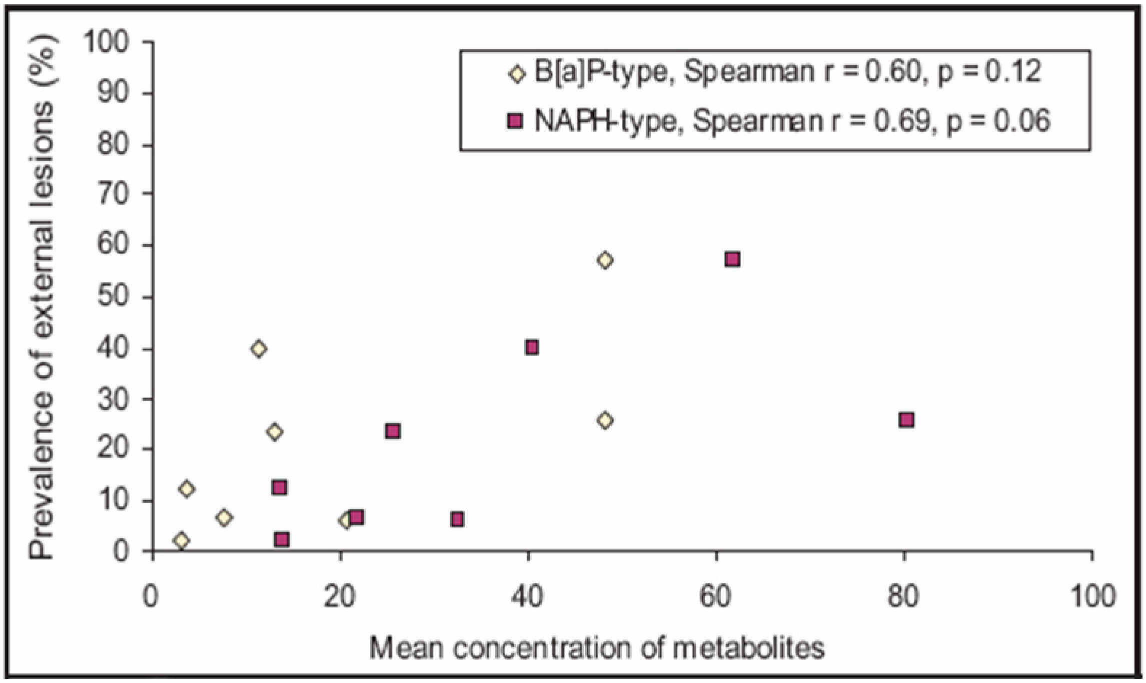

Figure 4. **Prevalence of external raised growths in brown bullhead from Lake Erie tributaries compared to PAH metabolite concentrations in bile (B[P] and NAPH-type unit are µg/mg protein.**
Source: Yang and Baumann, unpublished data.

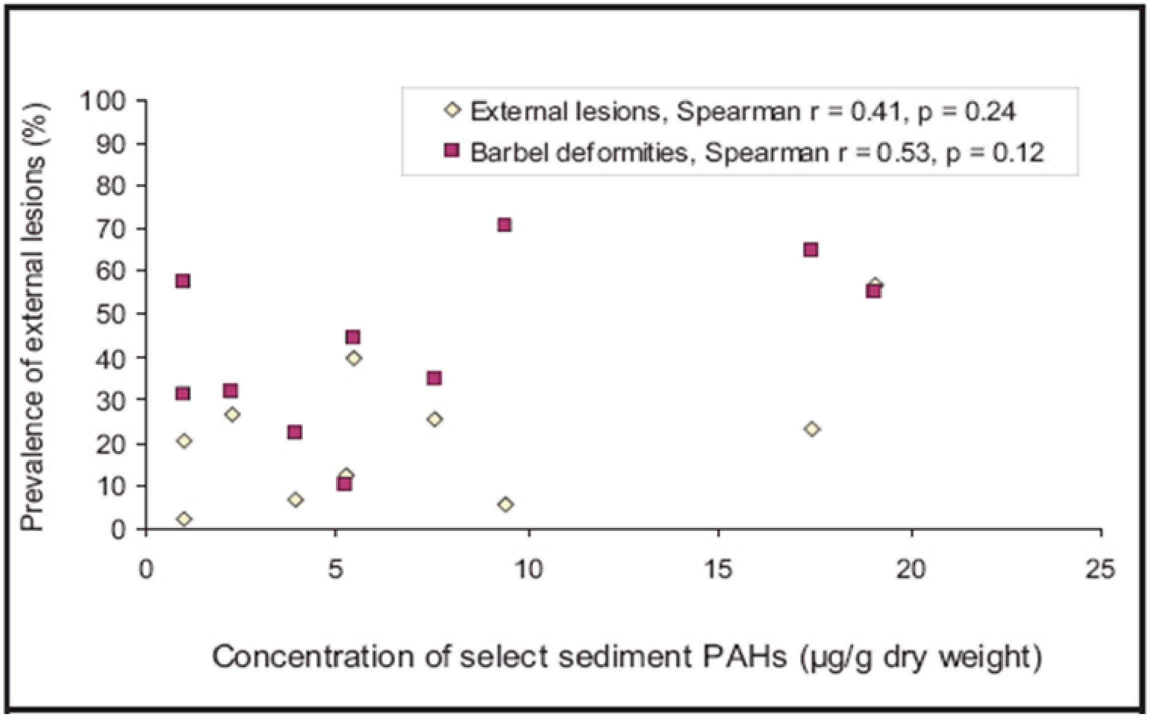

Figure 5. Prevalence of external raised growths and barbel deformities in brown bullhead from Lake Erie tributaries compared to PAH concentrations in sediment.
Source: Yang and Baumann, unpublished data.

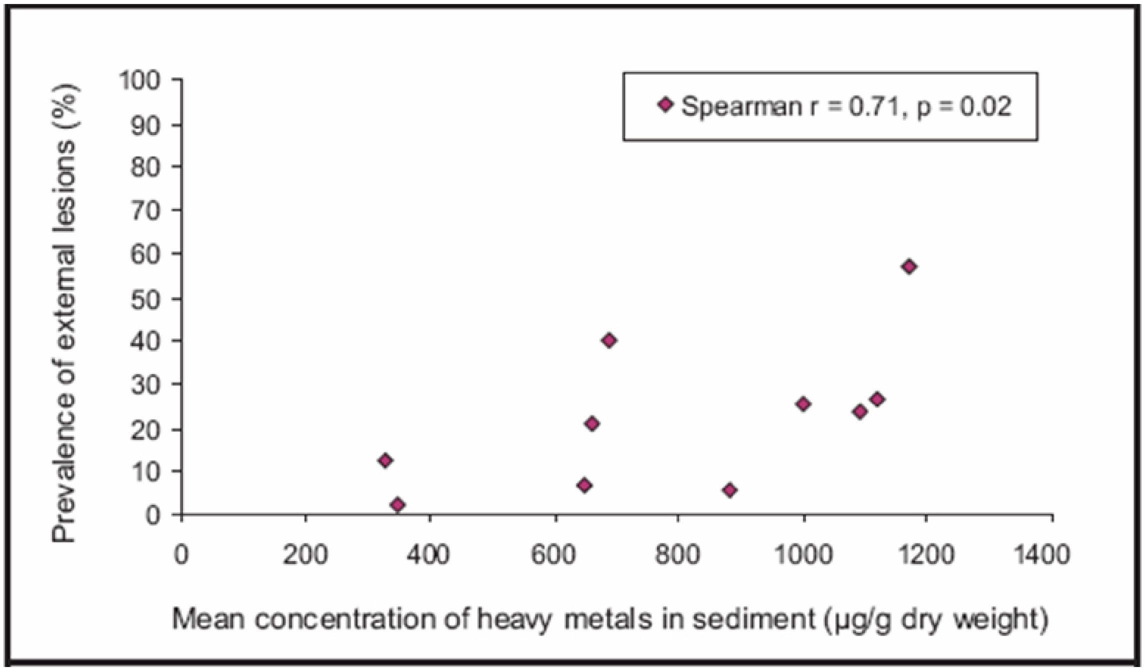

Figure 6. Prevalence of external raised growths in brown bullhead from Lake Erie tributaries compared to concentrations of heavy metals in sediment.
Source: Yang and Baumann, unpublished data.

Status of Lake Sturgeon in the Great Lakes
Indicator #125

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Primary Factors Determining Status and Trend: There are remnant populations in each basin of the Great Lakes, but few of these populations are large. Much progress has been made in recent years learning about population status in many tributaries. Confirmed observations and captures of lake sturgeon are increasing in all lakes. Stocking is contributing to increased abundance in some areas. There remains a need for information on some remnant spawning populations. Little is known about the juvenile life stage. In many areas habitat restoration is needed as spawning and rearing habitat has been destroyed, altered or access is blocked.

Lake by Lake Assessment

Lake Superior

Status: Mixed
Trend: Improving or Undetermined
Primary Factors Determining Status and Trend: Lake sturgeon abundance shows an increasing trend in a few remnant populations and where stocked in the Ontonagon and St. Louis rivers. Lake sturgeons currently reproduce in at least 10 of 21 known historic spawning tributaries.

Lake Michigan

Status: Mixed
Trend: Improving and Undetermined
Primary Factors Determining Status and Trend: Remnant populations persist in at least 8 tributaries having unimpeded connections to Lake Michigan. Successful reproduction has been documented in six rivers and abundance has increased in a few in recent years. Active rehabilitation has been initiated through rearing assistance in 1 remnant population and reintroductions have been initiated in three rivers.

Lake Huron

Status: Mixed
Trend: Improving and Undetermined
Primary Factors Determining Status and Trend: Current lake sturgeon spawning activity is limited to five tributaries, four in Georgian Bay and the North Channel and one in Saginaw Bay. Abundant stocks of mixed sizes are consistently captured in the North Channel, Georgian Bay, southern Lake Huron and Saginaw Bay.

Lake Erie

Status: Poor
Trend: Undetermined
Primary Factors Determining Status and Trend: Current lake sturgeon spawning activity is unknown except for three spawning areas identified in the Detroit and St. Clair Rivers. The western basin of Lake Erie, the North Channel of the St. Clair River and Anchor Bay in Lake St. Clair appear to be nursery areas for juveniles. In the central and eastern basins lake sturgeon are scarcer.

Lake Ontario

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	Lakewide incidental catches since 1995 indicate a possible improvement in their status. Spawning occurs in the Niagara River, Trent River, and possibly the Black River. There are sizeable populations within the St. Lawrence River system. Stocking for restoration began in 1995 in New York.

Purpose

- Lake sturgeon was a key component of the nearshore benthivore fish community and their presence and abundance indicates the health and status of that component of the Great Lakes ecosystem.

Ecosystem Objective

Lake sturgeon is identified as an important species in the Fish Community Objectives for each of the Great Lakes. Lake Superior has a lake sturgeon rehabilitation plan, and many of the Great Lakes States have lake sturgeon recovery/rehabilitation plans which call for increasing numbers of lake sturgeon beyond current levels. [Conserve, enhance or rehabilitate self-sustaining populations of lake sturgeon where the species historically occurred and at a level that will permit all State, Provincial and Federal delistings.]

State of the Ecosystem

Background

Lake sturgeon, *Acipenser fulvescens*, were historically abundant in the Great Lakes with spawning populations using many of the major tributaries, connecting waters, and shoal areas across the basin. Prior to European settlement of the region, they were a dominant component of the nearshore benthivore fish community, with populations estimated in the millions in each of the Great Lakes (Baldwin et al. 1979). In the mid- to late-1800s, they contributed significantly as a commercial species ranking among the five most abundant species in the commercial catch (Baldwin et al. 1979, Figure 1).

The decline of lake sturgeon populations in the Great Lakes was rapid and commensurate with habitat destruction, degraded water quality, and intensive fishing associated with settlement and development of the region. Sturgeon were initially considered a nuisance species of little value by European settlers, but by the mid-1800s, their value as a commercial species began to be recognized and a lucrative fishery developed. In less than 50 years, their abundance had declined sharply, and since 1900, they have remained a highly depleted species of little consequence to the commercial fishery. Sturgeon are now extirpated from many tributaries and waters where they once spawned and flourished (Figure 2 and Figure 3). They are considered rare, endangered, threatened, or of watch or special concern status by the various Great Lakes fisheries management agencies. Their harvest is currently prohibited or highly regulated in most U.S. and Canadian waters of the Great Lakes.

Status of Lake Sturgeon

Efforts are continuing by many agencies and organizations to gather information on remnant spawning populations in the Great Lakes. Most sturgeon populations continue to sustain themselves at a small fraction of their historical abundance. In many systems, access to spawning habitat has been blocked, and other habitats have been altered. However, there are remnant populations in each basin of the Great Lakes, and some of these populations are large in number

(10’s of thousands of fish, Figure 3). Genetic analysis has shown that Great Lakes populations are regionally structured and show significant diversity within and among lakes.

Lake Superior: The fish community of Lake Superior remains relatively intact in comparison to the other Great Lakes (Bronte et al. 2003). Historic and current information indicate that at least 21 Lake Superior tributaries supported spawning lake sturgeon populations (Harkness and Dymond 1961; Auer 2003; Holey et al. 2000). Lake sturgeons currently reproduce in at least 10 of these tributaries. Sturgeon populations in Lake Superior continue to sustain themselves at a small fraction of their historical abundance.

Current populations in Lake Superior are reduced from historic levels and none meet all rehabilitation targets. The number of lake sturgeon in annual spawning runs has been estimated over a multi-year period to range from 200-375 adults in the Sturgeon River, (Hay-Chmielewski and Whelan 1997; Holey et al. 2000), 200-350 adults in the Bad River in 1997 and 1998 (U.S. Fish and Wildlife Service, Ashland Fishery Resource Office, USFWS, 2800 Lake Shore Drive, Ashland, Wisconsin, 54806, unpublished data), and 140 adults in the Kaministiquia River, Ontario (Stephenson 1998). Estimates of lakewide abundance are available from the period during or after targeted commercial harvests in the 1880s. Using data from Baldwin et al. (1979), Hay-Chmielewski and Whelan (1997) estimated that historic lake sturgeon abundance in Lake Superior was 870,000 individuals of all ages. If the Rehabilitation Plan target of 1,500 adults were met in all 21 tributaries, the minimum lakewide abundance of adult fish would be 31,500.

Radio telemetry studies suggest that a river resident population inhabits the Kaministiquia River (Mike Friday, OMNR, Upper Great Lakes Management Unit-Lake Superior, 435 James St. South, Thunder Bay, Ontario P7E 6S8, personal communication). The Pic River also has the potential to support a river resident population. Juvenile lake sturgeon index surveys conducted by the Great Lakes Indian Fish and Wildlife Commission and U.S. Fish and Wildlife Service in Wisconsin waters show a gradually increasing trend in catch per unit effort from 1994-2002 (Table 1). Since 2001, sturgeon spawning surveys have been conducted for the first time in 8 tributaries. Genetic analysis has shown that lake sturgeon populations in Lake Superior are significantly different from those in the other Great Lakes. Currently, there is no commercial harvest of lake sturgeon allowed in Lake Superior. Regulation of recreational and subsistence/home use harvest in Lake Superior varies by agency.

Lake Michigan: Sturgeon populations in Lake Michigan continue to sustain themselves at a small fraction of their historical abundance. An optimistic estimate of the lakewide adult abundance is less than 5,000 fish, well below 1% of the most conservative estimates of historic abundance (Hay-Chmielewski and Whelan 1997). Remnant populations currently are known to spawn in waters of at least 8 tributaries having unimpeded connections to Lake Michigan (Schneeberger et al 2005). Two rivers, the Menominee and Peshtigo, appear to support annual spawning runs of 200 or more adults, and four rivers, the Manistee, Muskegon, Fox and Oconto, appear to support annual spawning runs of between 25 and 75 adults. Successful reproduction has been documented in all six of these rivers, although actual recruitment levels remain unknown. However, abundance in some of these rivers appears to be increasing in recent years. Two other rivers, the Manistique and Kalamazoo, appear to have annual spawning runs of less than 25 fish, and reproductive success remains unknown. Lake sturgeon have been observed during spawning times in a few other Lake Michigan tributaries such as the St. Joseph, Grand and Millecoquins, and near some shoal areas where sturgeon are thought to have spawned historically. It is not known if spawning occurs regularly in these systems, however, and their status is uncertain.

Lake Huron: Lake sturgeon populations continue to be well below historical levels. Spawning has been identified in the Garden, Mississaugi and Spanish rivers in the North Channel, in the Nottawasaga River in Georgian Bay and in the Rifle River in Saginaw Bay. Adult spawning populations for each of these river systems are estimated to be in the ten's and are well below rehabilitation targets (Hay-Chmielewski and Whelan 1997; Holey et al. 2000). Barriers on Michigan tributaries to Lake Huron continue to limit successful rehabilitation. Stocks of lake sturgeon in Lake Huron are monitored primarily through the volunteer efforts of commercial fishers cooperating with the various resource management agencies. To date the combined efforts of researchers in U.S. and Canadian waters has resulted in over 6,600 sturgeon tagged in Saginaw Bay, southern Lake Huron, Georgian Bay and the North Channel, with relatively large stocks of mixed sizes being captured at each of these general locations. Tag recoveries and telemetry studies indicate that lake sturgeon are moving within and between jurisdictional boundaries and between lake basins, supporting the need for more cooperative management between the states and between the U.S. and Canada. The Saginaw River watershed and the St. Mary's River systems are being assessed for spawning, both projects are ongoing and will continue through 2007. Similar research is being planned for the Thunder and Rifle Rivers in Michigan.

Lake Erie: Lake sturgeon populations continue to be well below historical levels. Spawning has been identified at two locations in the St. Clair River and at one location in the Detroit River (Manny and Kennedy 2002). Tag recovery data and telemetry research indicates that a robust lake sturgeon stock (> 45,000 fish) reside in the North Channel of the St. Clair River and Lake St. Clair (Thomas and Haas 2002). The North Channel, Anchor Bay and the western basin of Lake Erie have been identified as nursery areas as indicated by consistent catches in commercial and survey fishing gears. In the central and eastern basins of Lake Erie lake sturgeon are scarcer with only occasional catches of sub-adult or adult lake sturgeon in commercial fishing nets and none in research nets. A botulism-related die off in 2001 and 2002, and declines in sightings by anglers and others near Buffalo indicate a possible decline in population abundance of lake sturgeon in Lake Erie. Research is scheduled in 2007 to identify if spawning stocks of sturgeon are using reputed historic spawning sites in the lower Detroit River and the Maumee River. Research efforts will continue to focus on identifying new spawning locations, genetic difference between stocks, habitat requirements, and migration patterns.

Lake Ontario: Lake Ontario has lake sturgeon spawning activity documented in two major tributaries (Niagara River and Trent River) and suspected in at least one more (Black River) on an infrequent basis. There is no targeted assessment of lake sturgeon in Lake Ontario, but incidental catches in research nets have occurred since 1997 (Ontario Ministry of Natural Resources 2004) and 1995 (Eckert 2004), indicating a possible improvement in population status. Age analysis of lake sturgeon captured in the lower Niagara River indicates successful reproduction in the mid-1990s. New York State Department of Environmental Conservation initiated a stocking program in 1995 to recover lake sturgeon populations. Lake sturgeon have been stocked in the St. Lawrence River and some of its tributaries, inland lakes in New York, and the Genesee River. There are sizeable populations within the St. Lawrence River system, most notably the Des Prairies River, Lac St. Pierre and the St. Maurice River. However, access is inhibited for many of the historical spawning grounds in tributaries by small dams and within the St. Lawrence River by the Moses-Saunders Dam.

Pressures

Low numbers or lack of fish (where extirpated) is itself is a significant impediment to recovery in many spawning areas. Barriers that prevent lake sturgeon from moving into tributaries to spawn are a major problem. Predation on eggs and newly hatched lake sturgeon by non-native predators may also be a problem. The genetic structure of remaining populations is being studied by university researchers and fishery managers, and this information will be used to guide future management decisions. With the collapse of the Caspian Sea sturgeon populations, black market demand for sturgeon caviar could put tremendous pressure on Great Lakes lake sturgeon populations. An additional concern for lake sturgeon in Lake Erie and Lake Ontario is the presence of high densities of round gobies and the spread of Botulism Type E, which produced a die-off of lake sturgeon in Lake Erie in 2001 and 2002. Botulism may also have been the cause of similar mortalities observed in Lake Ontario in 2003 and in Green Bay of Lake Michigan.

Management Implications

Lake sturgeon are an important native species that are listed in the Fish Community Objectives for all of the Great Lakes. Many of the Great Lakes states and provinces either have or are developing lake sturgeon management plans promoting the need to inventory, protect and restore the species to greater levels of abundance.

While overexploitation removed millions of adult fish, habitat degradation and alteration eliminated traditional spawning grounds. Current work is underway by state, federal, tribal, provincial and private groups to document active spawning sites, assess habitat condition and availability of good habitat, and determine the genetics of remnant Great Lakes lake sturgeon populations.

Several meetings and workshops have been held focusing on identifying the research and assessment needs to further rehabilitation of lake sturgeon in the Great Lakes (Holey et al. 2000), and a significant amount of research and assessment directed towards these needs has occurred in the last 10 years. Among these is the research to better define the genetic structuring of Great Lakes lake sturgeon populations, and genetics-based rehabilitation plans are being developed to help guide reintroduction and rehabilitation efforts being implemented across the Great Lakes. Research into new fish passage technologies that will allow safe upstream and downstream passage around barriers to migration also have been underway for several years. Many groups are continuing to work to identify current lake sturgeon spawning locations in the Great Lakes, and studies are being initiated to identify habitat preferences for juvenile lake sturgeon (ages 0-2).

Comments from the author(s)

Research and development is needed to determine ways to pass lake sturgeon at man-made barriers on rivers. In addition, there are significant, legal, logistical, and financial hurdles to overcome in order to restore degraded spawning habitats in connecting waterways and tributaries to the Great Lakes. More monitoring is needed to determine the current status of Great Lakes lake sturgeon populations, particularly the juvenile life stage. Cooperative effort between law enforcement and fishery managers is required as world pressure on sturgeon stocks will result in the need to protect large adult lake sturgeon in the Great Lakes.

Acknowledgments

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Figure 3. Current distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

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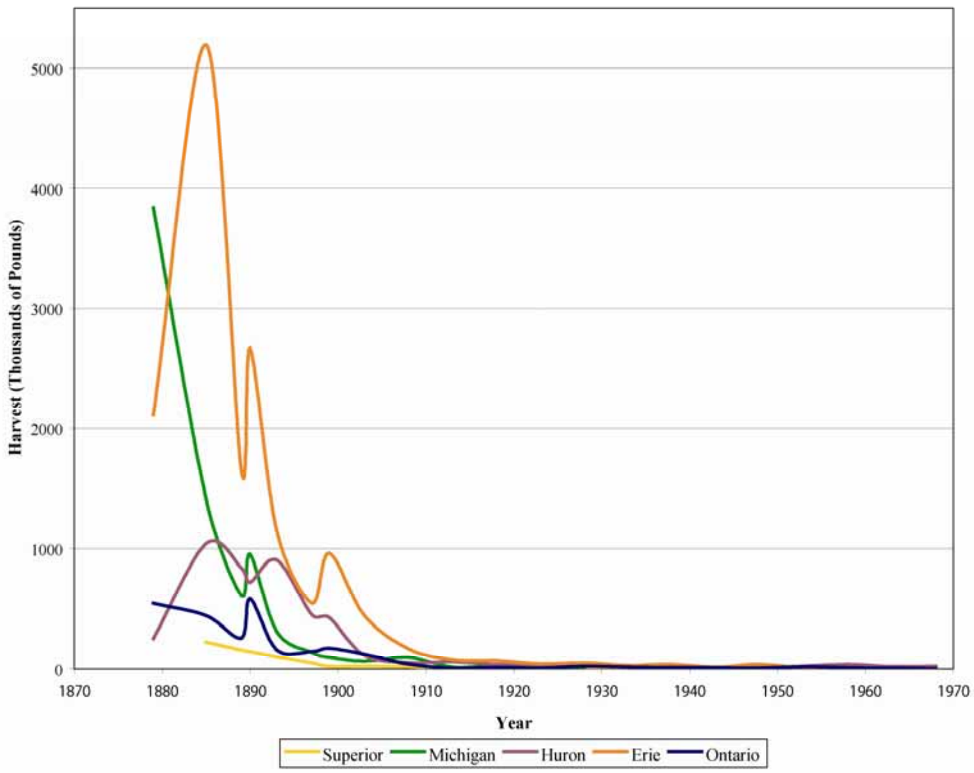

Figure 1. Historic lake sturgeon harvest from each of the Great Lakes.
Source: Baldwin *et al*. 1979

Year	Month	CPE
1994	6	0.333333
1995	6	1
1996	6	0.714286
1997	6	1.142857
1998	6	1.769231
1999	6	2.5
2000	6	2.25
2001	6	4.5
2002	6	5.5

Table 1. Trends in juvenile lake sturgeon CPE during June in Lake Superior near the mouth of the Bad River.

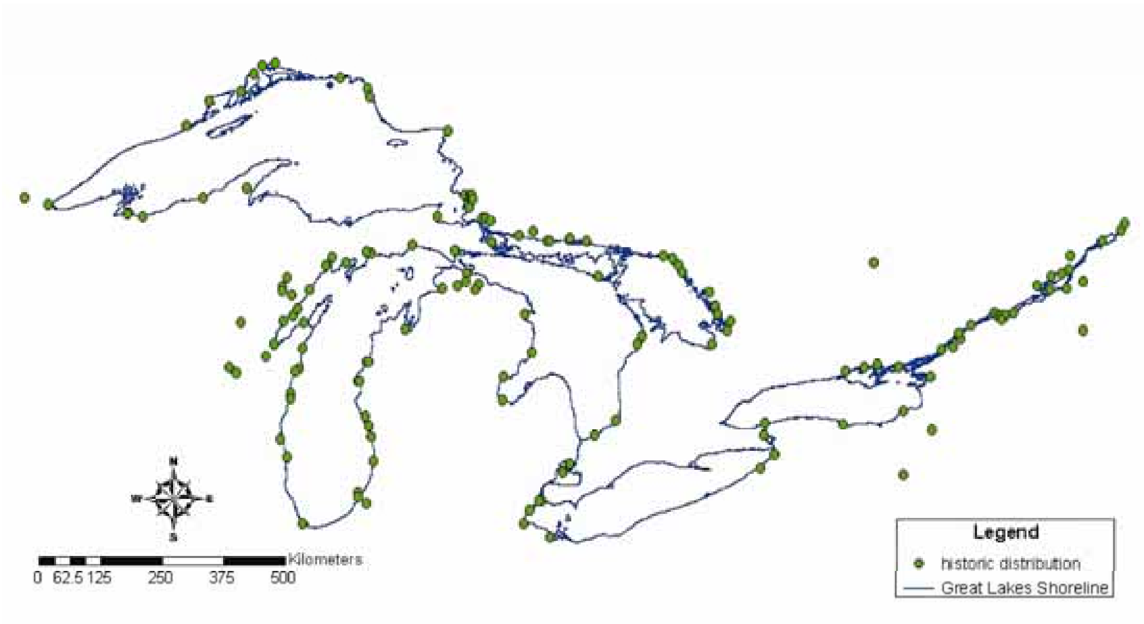

Figure 2. Historic distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

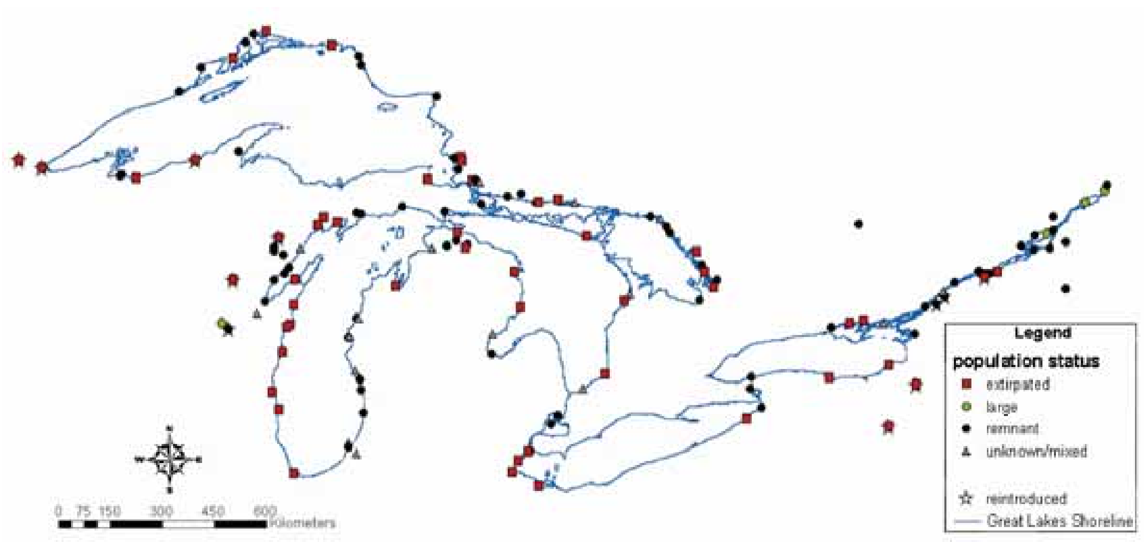

Figure 3. Current distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

Commercial/Industrial Eco-Efficiency Measures

Indicator #3514

Assessment: Not Assessed

Purpose

- To assess the institutionalized response of the commercial/industrial sector to pressures imposed on the ecosystem as a result of production processes and service delivery.

Ecosystem Objective

The goal of eco-efficiency is to deliver competitively priced goods and services that satisfy human needs and increase quality of life, while progressively reducing ecological impacts and resource intensity throughout the lifecycle, to a level at least in line with the earth's estimated carrying capacity (WBCSD 1996). In quantitative terms, the goal is to increase the ratio of the value of output(s) produced by a firm to the sum of the environmental pressures generated by the firm (OECD *et al.* 1998).

State of the Ecosystem

Background

This indicator report for eco-efficiency is based upon the public documents produced by the 24 largest employers in the basin which report eco-efficiency measures and implement eco-efficiency strategies. The 24 largest employers were selected as industry leaders and as a proxy for assessing commercial/industrial eco-efficiency measures. This indicator should not be considered a comprehensive evaluation of all the activities of the commercial/industrial sector, particularly small-scale organizations, though it is presumed that many other industrial/commercial organizations are implementing and reporting on similar strategies.

Efforts to track eco-efficiency in the Great Lakes basin and in North America are still in the infancy stage. This is the first assessment of its kind in the Great Lakes region. It includes 24 of the largest private employers, from a variety of sectors, operating in the basin. Participation in eco-efficiency was tabulated from publicly available environmental reporting data from 10 Canadian companies and 14 American companies based in (or with major operations in) the Great Lakes basin.

Tracking of eco-efficiency indicators is based on the notion that what is measured is what gets done. The evaluation of this indicator is conducted by recording presence/absence of reporting related to performance in seven eco-efficiency reporting categories (net sales, quantity of goods produced, material consumption, energy consumption, water consumption, greenhouse gas emissions, emissions of ozone depleting substances (WBCSD 2002)). In addition, the evaluation includes an enumeration of specific initiatives that are targeted toward one or more of the elements of eco-efficiency success (material intensity, energy intensity, toxic dispersion, recyclability and product durability (WBCSD 2002)).

State of Eco-Efficiency

Of the 24 companies surveyed, 10 reported publicly (available online or through customer service inquiry) on at least some measures of eco-efficiency. Energy consumption and, to some extent, material consumption were the most commonly reported measures. Of the 10 firms that reported on some elements of eco-efficiency, three reported on all seven measures.
Of the 24 companies surveyed, 19 (or 79%) reported on implementation of specific eco-efficiency related initiatives. Two companies reported activities related to all five success areas. Reported initiatives were most commonly targeted toward improved recycling and improved energy efficiency.

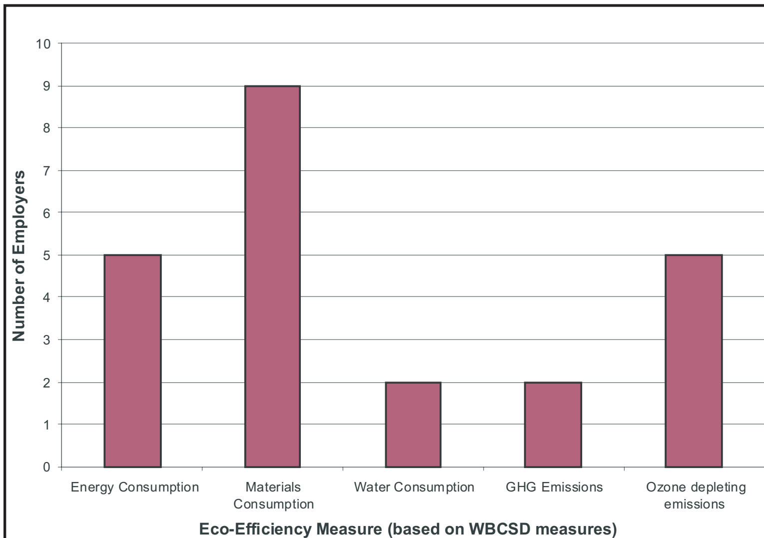

Figure 1. Number of the 24 largest employers in the Great Lakes basin that publicly report eco-efficiency measures. GHG = green house gas. Source: WBCSD = World Business Council for Sustainable Development

Overall, companies in the manufacturing sector tended to provide more public information on environmental performance than the retail or financial sectors. At the same time, nearly all firms expressed a commitment to reducing the environmental impact of their operations. A select number of companies, such as Steelcase Inc. and General Motors in the U.S. and Nortel Networks in Canada, have shown strong leadership in comprehensive, easily accessed, public reporting on environmental performance. Others, such as Haworth Inc. and Quad/Graphics, have shown distinct creativity and innovation in implementing measures to reduce their environmental impact.

The concept of eco-efficiency was defined in 1990 but was not widely accepted until several years later. Specific data on commercial/industrial measures are only just being implemented, therefore it is not yet possible to determine trends in eco-efficiency reporting. In general, firms appear to be working to improve the efficiency of their goods and service delivery. This is an important trend as it indicates the growing ability of firms to increase the quantity/number of goods and services produced for the same or a lesser quantity of resources per unit of output.

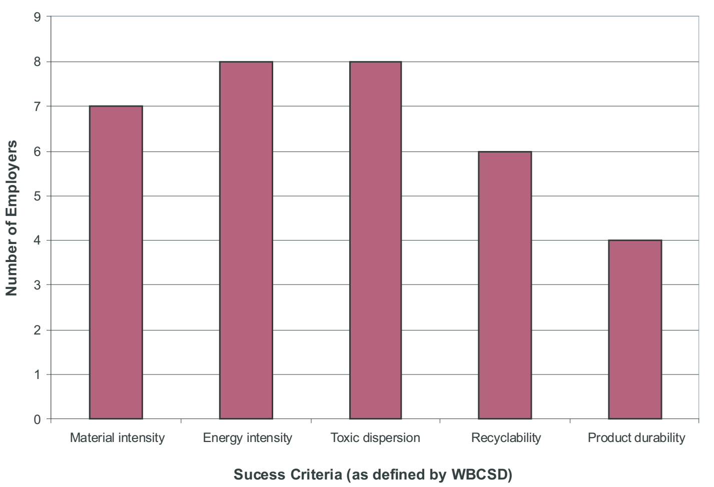

Figure 2. Number of the 24 largest employers in the Great Lakes basin that publicly report initiatives related to eco-efficiency success criteria.
Source: WBCSD = World Business Council for Sustainable Development

While one or more eco-efficiency measures are often included in environmental reporting, only a few firms recognize the complete eco-efficiency concept. Many firms recognize the need for more environmentally sensitive delivery of goods and services; however, the implementation of more environmentally efficient processes appears narrow in scope. These observations indicate that more could be done toward more sustainable goods and services delivery.

Pressures
Eco-efficiency per unit of production will undoubtedly increase over time, given the economic, environmental and public relations incentives for doing so. However, as Great Lakes populations and economies grow, quantity of goods and services produced will likely increase. If production increases by a greater margin than eco-efficiency improvements, then the overall commercial / industrial environmental impact will continue to rise. Absolute reductions in the sum of environmental pressures are necessary to deliver goods and services within the earth's carrying capacity.

Management Implications
The potential for improving the environmental and economic efficiency of goods and services delivery is unlimited. To meet the ecosystem objective, more firms in the commercial / industrial sector need to recognize the value of eco-efficiency and need to monitor and reduce the environmental impacts of production.

Acknowledgments
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Tom Van Camp and Nicolas Dion of Industry Canada provided several data resources.
Many of the firms surveyed in this report also contributed environmental reports and other corporate information. Chambers of commerce in many states and provinces around the Great Lakes provided employment data.

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Authors' Commentary
By repeating this evaluation at a regular interval (i.e. every 2 or 4 years), trends in industrial / commercial eco-efficiency can be determined. The sustainability of goods and service delivery in the Great Lakes basin can only be determined if social justice measures are also included in commercial/industrial sector assessments. The difficulty in assessing the impacts of social justice issues precludes them from being included in this report, however, such social welfare impacts should be included in future indicator assessment.

Last Updated
State of the Great Lakes 2003

Drinking Water Quality
Indicator #4175

Overall Assessment

Status:	**Good**
Trend:	**Unchanging**
Primary Factors Determining Status and Trend	Based on the information provided in the annual CC/WQRs and the Ontario annual reports from the DWSs, the overall quality of the finished drinking water in the Great Lakes Basin can be considered good. Because very few violations of federally, provincially, or state regulated MCLs, MACs, or treatment techniques occurred, the WTPs/DWSs are, in fact, employing treatment techniques that are successfully treating water. As such, the potential risk of human exposure to the noted chemical and/or microbiological continents, and any associated health effects, is generally low.

Lake-by-Lake Assessment

Lake Superior

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Michigan

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Huron

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Erie

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Ontario

Status:	Not Assessed

Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Purpose

- To evaluate the chemical and microbial contaminant levels in source water and in treated water; and
- To assess the potential for human exposure to drinking water contaminants and the effectiveness of policies and technologies to ensure safe drinking water.

Ecosystem Objective

The ultimate goal of this indicator is to ensure that all drinking water provided to the residents of the Great Lakes basin is protected at its source, and treated in such a way that it is safe to drink without reservations. As such, the treated water should be free from harmful chemical and microbiological contaminants. This indicator supports Great Lakes Quality Agreement Annexes 1, 2, 12, and 16.

State of the Ecosystem

Background

The information provided by the United States for this report focuses mainly on finished, or treated, drinking water. This format was chosen as the focus for U.S. reporting in order to adapt to the recommendations of the Environmental Health Indicator Project (www.cdc.gov/nceh/indicators/default.htm). Additionally, the U.S. is in the process of establishing an inclusive national drinking water database, which will include raw, or source water data, thus providing an extensive array of information to all WTPs/DWSs, researchers, and the general public. The information provided by Canada focuses on both finished and raw, or source, water.

In the U.S., the Safe-Drinking Water Act Re-authorization of 1996 requires all drinking water utilities to provide yearly water quality information to their consumers. To satisfy this obligation, U.S. Water Treatment Plants (WTPs) produce an annual Consumer Confidence/Water Quality Report (CC/WQR). These reports provide information regarding: source water type (i.e. lake, river or groundwater), the water treatment process, contaminants detected in the finished water, any violations that occurred, and other relevant information. For this indicator report the CC/WQRs were collected from 59 WTPs for the operational year 2004 (2005 when available). Furthermore, the U.S. based Safe Drinking Water Information System (SDWIS) was also used as a means to verify information presented in the reports and to provide any other relevant information, where CC/WQRs were not yet available.

The data used for the Canadian component of the report were provided by the Ontario Ministry of the Environment and include results from two program areas. Data collected as part of the Drinking Water Surveillance Program (DWSP) was provided for the period 2001/2002. DWSP is a voluntary partnership program with municipalities that monitors drinking water quality. Ontario's Drinking Water Systems Regulation (O. Reg. 170/03), made under the Safe Drinking Water Act, 2002, requires that the owner of a Drinking Water Systems (DWS) prepare an annual report on the operation of the system and the quality of its water. DWSs must provide the Ontario Ministry of the Environment (OMOE) with their drinking water quality data. Data from January to June 2004, collected as part of this regulatory framework from 74 DWSs, were also provided for analysis.

There are several sources of drinking water within the Great Lakes basin which include; the Great Lakes themselves, smaller lakes/reservoirs, rivers, streams, ponds, and groundwater i.e. springs and wells. However, these systems are vulnerable to contamination from several sources (chemical, biological, and radioactive). Substances that may be present in the source water include: microbial contaminants, such as viruses and bacteria; inorganic contaminants, such as salts and metals; pesticides and herbicides; organic chemical contaminants, including synthetic and volatile organic chemicals; and radioactive contaminants. After collection, the raw water undergoes a detailed treatment process prior to being sent to the distribution system where it is then dispersed to consumer taps. The treatment process involves several basic steps, which are often varied and repeated depending on the condition of the source water. It is important to note that raw water can also affect the finished water that is consumed. Good quality raw water is an important part of a multi-barrier approach to assuring the safety and quality of drinking water.

Status of Drinking Water in the Great Lakes Basin

Ten drinking water parameters were chosen to provide the best assessment of drinking water quality in the Great Lakes Basin, which include several chemical parameters, microbiological parameters, and other indicators of potential health hazards. These parameters are regulated by an established standard, which when exceeded, has the potential to have serious affects on human health. The U.S. Environmental Protection Agency (USEPA) defines this regulated standard as the Maximum Contaminant Level (MCL), or the highest level of a contaminant that is allowed in drinking water. The Ontario drinking water standards are described by the Maximum Acceptable Concentration (MAC), which is established for parameters that when present above a certain concentration, have known or suspected health effects, and the Interim Maximum Acceptable Concentration (IMAC), which is established for parameters either when there is insufficient toxicological data to establish a MAC with reasonable certainty, or when it is not feasible, for practical reasons, to establish a MAC at the desired level.

Chemical Contaminants

The chemical contaminants of concern include; atrazine, nitrate, and nitrite. Exposure to these contaminants above the regulated standards has the potential to negatively affect human health.

Atrazine-Atrazine, which has been widely used as an organic herbicide, can enter source water though agricultural runoff and/or wastewater from manufacturing facilities. Consumption of drinking water that contains atrazine in excess of the regulated standard, for extended periods of time, can potentially lead to health complications. The USEPA has set the MCL for atrazine at 3 parts per billion (ppb) and the Ontario Drinking water standards specify the IMAC to be 5 ppb, which is the lowest level at which WTPs/DWSs could reasonably be required to remove this contaminant given the present technology and resources.

In the U.S., atrazine was infrequently detected in finished water supplies, and was only found in finished water originating from Lake Erie, rivers, and small lakes/reservoirs. However when detected, it was found at levels that did not exceed the MCL. Violations of monitoring requirements were reported for two WTPs for failure to monitor atrazine and other contaminants between February and June 2004 and during July 2004, respectively. Therefore, as indicated by the annual CC/WQRs there is a low risk of human exposure to atrazine.

In Ontario, data from the 2003/2004 DWSP indicated that 22 percent of the water samples collected had trace amount of atrazine present. However, the highest level detected was only 0.59 ppb (about one order of magnitude less than the IMAC), which was identified from a raw water source located within an agricultural watershed.

Nitrogen-Nitrogen is a naturally occurring nutrient that is also used in many agricultural applications. However, in natural waters most nitrogenous material tends to be converted into nitrates, which when ingested at levels exceeding the MCL or MAC can cause serious health effects, particularly to infants. The USEPA has set the MCL for nitrate at 10 parts per million (ppm) and nitrite at 1 ppm and the province of Ontario has set the MAC for nitrate at 10 ppm and nitrite at 1 ppm.

In the U.S., nitrate was detected in over 70 percent of the finished water supplies which originated from WTPs using all sources of water except Lake Huron. However, it was never found at levels that exceeded the MCL and therefore, while there is some risk of exposure to nitrate, it is not likely to lead to serious health complications.

In Ontario, over 90 percent of the of the water samples contained nitrates; however, the highest level detected was 9.11 ppm, from a raw ground water sample. As such, there is a risk of exposure to nitrates, especially in agricultural areas, but it is not likely to cause health complications as detected levels never exceeded the Ontario contamination standard.

In the U.S., nitrite was rarely detected in finished water supplies. It was only found in finished water for WTPs which use rivers and small lakes/reservoirs as source water. As such, there is only a small potential for human exposure to nitrite from drinking water. No MCL or monitoring regulation violations were reported for nitrites.

Over fifty percent of the water samples contained a measurable amount of nitrite according to the Ontario drinking water system reports. However, the highest value for this contaminant only reached 0.365 ppm, which is lower than the Ontario MAC and the highest value detected last year (0.434 ppm).

Microbiological Parameters

The microbiological parameters evaluated include total coliform, *Escherichia coli (E. coli)*, *Giardia*, and *Cryptosporidium.* These microbial contaminants are included as indicators of water quality, but also as an indication of the presence of hazardous and possibly fatal pathogens in the water.

Total Coliform-Coliforms are a broad class of bacteria that are ubiquitous in the environment and in the feces of humans and animals. The USEPA has set a MCL for total coliform at 5% of the total monthly samples (e.g. for water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month). Canada has set an

MCL of 0 colony forming units (CFU) for DWSs. Both Canada and the U.S. require additional analysis of positive total coliform samples to determine if specific types of coliform, such as fecal coliform or *E coli*, are present.

Escherichia coli (E. coli)-E. coli is a type of thermo tolerant (fecal) coliform bacteria that is generally found in the intestines, and fecal waste, of all animals, including humans. This type of bacteria commonly enters source water through contaminated runoff, which is often the result of precipitation. Detection of *E. coli* in water strongly indicates recent contamination of sewage or animal waste, which may contain many types of disease-causing organisms. It is mandatory for all WTPs to inform consumers if *E. coli* is present in their drinking and/or recreational water (U.S. waters only).

In the U.S., the presence of total coliform was detected in finished water from WTPs using all source water types, except Lake Superior. It was repeatedly detected in finished water from WTPs using Lake Michigan, groundwater, rivers, and small lakes/reservoirs as source water. Between July 2004 and October 2005, there were four violations with regard to total coliform levels exceeding the MCL. As such, repeat samples were collected at the same locations as the positive total coliform bacteria sample and at nearby locations to determine if the original positive sample indicated a localized water problem, or a sampling or testing error. However, samples from two of these WTPs tested positive for either fecal coliform or *E. coli*. Additionally, violations of monitoring requirements of USEPA's Total Coliform Rule (TCR) were reported in one WTP, for not collecting enough repeat samples after coliform bacteria was detected in the monthly routine samples. Although there is a potential for human exposure to total coliform, it is not likely to be a human health hazard in itself. However, the presence of coliform bacteria, especially at levels exceeding the MCL, indicates the possibility that microbial pathogens may be present, and this can be hazardous to human health.

In Ontario, total coliform was detected in many of the raw water samples; however only a few treated water samples contained this contaminant. Furthermore, *E. coli* was identified in raw water samples, which originating mostly from small lakes and rivers, in small amounts. However, the presence of *E. coli* was not identified in finished water supply, indicating that the treatment facilities are working adequately to remove both of these microbiological parameters.

Giardia and *Cryptosporidium- Giardia* and *Cryptosporidium* are parasites that exist in water and when ingested may cause gastrointestinal illness in humans. The U.S. treated water standards, which controls the presence of these microorganisms in the treated water, dictate that 99% of *Cryptosporidium* should be physically removed by filtration. In addition, *Giardia* must be 99.9% removed and/or inactivated by filtration and disinfection. These regulations are confirmed by the levels of post treatment turbidity and disinfectant residual levels. Ontario has also adopted removal/inactivation for *Giardia* and *Cryptosporidium*, however, there is no data to report at this time.

In the U.S., neither *Giardia* nor *Cryptosporidium* were detected in finished water supplies from any of the WTPs. However, several of the CC/WQRs discussed the presence of these microorganisms in the source waters (Lake Erie, Lake Huron, Lake Michigan, Lake Ontario, small lakes/reservoirs). The presence of these organisms in raw water but not in finished water indicates that current treatment techniques are effective at removing these parasites from drinking water. Nevertheless, implementing measures to prevent or reduce microbial contamination from source waters should remain a priority. Even a well-operated WTP cannot ensure that drinking water will be completely free of *Cryptosporidium.* Furthermore, very low levels of *Cryptosporidium* may be of concern for the severely immuno-compromised because exposure can compound their illness.

The annual CC/WQRs indicate that there is a potential for consumers to be exposed to the aforementioned microbiological contaminants. However, total coliform was the most common microbiological contaminant detected. Furthermore, there were very few if any confirmed detections of the more serious contaminants including, *E. coli, Giardia,* and *Cryptosporidium,* in the finished water of the U.S.. As a result, it is not likely that consumption of drinking water containing these contaminants will lead to any serious health complications.

Treatment Technique Parameters
The treatment technique parameters evaluated include turbidity, total organic carbon (TOC) in the U.S. and dissolved organic carbon (DOC) in Canada. These parameters do not pose a direct danger to human health but often indicate other health hazards.

Turbidity-Turbidity is a measure of the cloudiness of water and can be used to indicate water quality and filtration efficiency. Higher turbidity levels, which can inhibit the effectiveness of the disinfection/filtration process and/or provide a medium for microbial growth, are associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. A significant relationship has been demonstrated between increased turbidity and the number of *Giardia* cysts and *Cryptosporidium* oocysts breaking through filters. USEPA's surface water treatment rules require WTPs using surface water or ground water under the direct influence of surface water must disinfect and filter their water. In the U.S., turbidity levels must not exceed 5 Nephelolometric Turbidity Units (NTU) at any time, while WTPs that filter must ensure that the turbidity go no higher than 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month. Ontario has set the aesthetic objective for turbidity at 5.0 NTU, at which point turbidity becomes visible to the naked eye.

In the U.S., turbidity data is difficult to assess due to the different requirements and regulations for WTPs depending on the source water and treatment technique used. However, there were no MCL or monitoring regulations violations reported from January 2004 to October 2005.

In Ontario, the 2003/2004 DWSP report indicated that 78 raw water samples, many of which originated from Lake St. Clair and the Detroit River, exceeded the aesthetic objective. Furthermore, one treated water sample exceed the aesthetic objective with a turbidity level of 11.1 NTU.

Total Organic Carbon-Although the presence of total organic carbon (TOC) in water does not directly imply a health hazard, the organic carbon can react with chemical disinfectants to form harmful byproducts. WTPs remove TOC from the water by using treatment techniques such as enhanced coagulation or enhanced softening. Conventional WTPs with excess TOC in the raw water are required to remove a certain percentage of the TOC depending upon the TOC and the alkalinity level of the raw water. The USEPA does not have a MCL for TOC.

In the U.S., TOC was detected in finished water from WTPs using all source water types, except Lake Superior. However, TOC data was difficult to assess due to the varying formats of CC/WQRs and the way data was presented. As such, it was difficult to quantitatively evaluate and compare the TOC levels reported by each WTP. Violations of monitoring requirements and/or failure to report the results were reported for one WTP from July to September 2005.

Dissolved Organic Carbon-Dissolved organic carbon (DOC) can indicate the potential possibility of water deterioration during storage and distribution. Acting as a growth nutrient, increased levels of carbon can aid in the proliferation of biofilm, or microbial cells that attach to the surface of pipes and multiply to form a layer of film or slime on the pipes, which can harbor and protect coliform bacteria from disinfectants. High DOC levels can also indicate the potential of chlorination by-products problems. The use of coagulant treatment or high pressure membrane treatment can be used to reduce DOC. The aesthetic objective for DOC in Ontario's drinking water is 5 ppm.

In Ontario, there were 110 DOC violations, 11.4 ppm being the highest level, identified from raw water sample; however, no treated water sample contained DOC levels exceeding the aesthetic objective. Most of the high DOC results came from raw water originating from small rivers and lakes.

Taste and Odor
While taste and odor do not necessarily reflect any health hazards, these water characteristics affect the consumer perception of the drinking water quality.

In the U.S., there were no reports of offensive taste or odors associated with the finished drinking water as indicated by the 2005 CC/WQRs.

In Ontario, there has been an increase in the number of reports associated with offensive taste and odor over the past several years; however, specific data is unavailable as it is difficult to quantitatively evaluate and compare results. Many drinking-water systems have now installed granular activated carbon filters to decrease the effect and intensity of these taste and odor events, which are due, in part, to the increased decomposition of blue-green algae in the Great Lakes (Ministry of Environment, 2004).

Summary
Based on the information provided in the annual CC/WQRs and the Ontario annual reports from the DWSs, the overall quality of the finished drinking water can be considered good. However, over the past several years there has been an increase in the quantity of contaminants found in raw source water in the Great Lakes Basin. The overall potential risk of human exposure to the noted chemical and/or microbiological continents, and any associated health effects, is generally low as very few violations of federally, provincially, or state regulated MCLs, MACs, or treatment techniques occurred. This indicates that the WTPs/DWSs are employing treatment techniques that are successfully treating water

Pressures

The greatest pressure to the quality of drinking water within the Great Lakes Basin would be degraded runoff. Several causes for this reduction in quality would including; the increasing rate of industrial development on or near water bodies, low-density urban sprawl, and agriculture - both crop and livestock operations. Point source pollution, from wastewater treatment plants for example, can also contribute to the contamination of raw water supplies and therefore can be considered an important pressure as well. Additionally, there is an emerging set of pressures such as newly introduced chemicals, chemicals of emerging concern (i.e. pharmaceuticals and personal care products (PPCPs), endocrine disruptors, antibiotics and antibacterial agents) and invasive species which might affect water quality; however to what extent is still unknown.

Management Implications

A more standardized, updated approach to monitoring contaminants and reporting data for drinking water needs to be established. Even though the USEPA has established an extensive list of contaminants, and their MCLs, newer parameters of concern might not be listed due to available resources or technology. Additionally, state monitoring requirements may differ; requiring only a portion of this list to be monitored. This would make trend analysis easier, and thus provide a more effective assessment of the potential health hazards associated with drinking water.

Furthermore, a more extensive monitoring program must be implemented in order to successfully correlate drinking water quality with the status of the Great Lakes Basin. Although the CC/WQRs provide useful information regarding the quality of finished drinking water, they merely depict the efficiency of the WTP, rather than the overall quality of the region. Additionally, by solely focusing on treated water, WTPs that rely on several type of source water will not provide accurate data with regard to contaminant origin. Therefore, in order to properly assess the state of the ecosystem, source water data would need to be reviewed.

Another concern for future efforts would be the adherence of a consistent guideline when identifying usable data; a guideline that obtains sufficient data while also providing adequate geographical coverage. In the U.S., data from WTPs serving a population of 50,000 or great was used, while data from all DWSs in Ontario serving a population of 10,000 or greater was analyzed. Furthermore, focusing on this criterion for WTPs only provides a fragmented view of the drinking water patterns in the Great Lakes Basin; however by sporadically including additional WTPs to expand the geographical coverage area, bias results may be introduced.

In addition to raw and treated water, some effort should also be made to analyze distributed water. Even though there are numerous precautions in place to ensure the quality of finished water, contamination is also possible during the distribution stage. Corrosion of copper or lead pipes and/or bacterial growth within these pipes could affect the overall quality of drinking water. Even though WTPs/DWSs are implementing actions to prevent or hinder such contamination, without sufficient data from distributed water supplies it is impossible to determine whether these efforts are effective or need to be altered.

Acknowledgments

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Consumer Confidence Reports

Akron Public Utilities Bureau – Annual Drinking Water Quality Report for 2005
Alpena Water Treatment Plant – 2005 Annual Drinking Water Quality Report
Aqua Ohio, Inc. PWS – 2005 Water Quality Report
Aqua Ohio – Mentor – 2005 Water Quality Report
Buffalo Water Authority – 2005 Annual Water Quality Report
City of Ann Arbor Water Utilities – 2005 Annual Report on Drinking Water
City of Battle Creek Public Works – 2005 Annual Water Quality Report
City of Cleveland Division of Water – 2006 Water Quality Report
City of Duluth Public Works and Utilities Department – 2005 Guide to Drinking Water Quality
City of Evanston – 2005 Water Quality Report
City of Kalamazoo – 2005 Water Quality Report
City of Kenosha Water Utility – 2005 Annual Drinking Water Quality Report
City of Marquette Water Filtration Plant – 2005 Annual Drinking Water Quality Report
City of Muskegon Water Filtration Plant – 2005 Annual Water Quality Report
City of Oshkosh – Drinking Water Quality Report 2005
City of Rochester – Water Quality Report 2005
City of Syracuse Department of Water – Annual Drinking Water Quality Report for 2005
City of Toledo Water Treatment Plant – 2005 Drinking Water Quality Report
City of Warren – 2005 Water Quality Report
City of Waukegan – 2006 Water Quality Report
City of Wyoming – 2005 Water Quality Report
Department of Utilities Appleton Water Treatment Facility – 2005 Annual Water Quality Report to our Community
Detroit Water & Sewer Department – 2005 Water Quality Report
Elmira Water Board – Annual Drinking Water Quality Report 2005
Elyria Water Department – 2005 Annual Water Quality Report
Erie County Water Authority – 2005 Water Quality Report

Erie Water Works (EWW) – Water Quality Report for Year 2005
Fort Wayne City Utilities – 2006 Annual Drinking Water Quality Report
Grand Rapids Water System – Water Quality Report 2005
Green Bay Water Utility – 2006 Annual Drinking Water Quality Report
Indiana-American Water Company, Inc. (Northwest Operations) – 2005 Annual Water Quality Report
Lansing Board of Water & Light – 2005 Annual Water Quality Report
Michael C. O'Laughlin Municipal Water Plant – Annual Drinking Water Quality Report for 2005
Milwaukee Water Works – 2005 Water Quality Report
Mohawk Valley Water Authority – 2005 Water Quality Report
Monroe County Water Authority (MCWA) – 2005 Annual Water Quality Report
Onondaga County Water Authority (OCWA) – 2005 Consumer Confidence Report & Annual Water Supply Statement
Port Huron Water Treatment Plant – 2005 Annual Drinking Water Quality Report
Saginaw Water Treatment Plant – Drinking Water Quality Report for 2005
South Bend Water Works – Water Quality Report 2005
The City of Chicago – Water 2005 Quality Report
Waterford Township – 2005 Annual Water Quality Report
Waukesha Water Utility – 2005 Consumer Confidence Report
Waukesha Water Utility – 2006 Consumer Confidence Report

Last updated
SOLEC 2006

Biological Markers of Human Exposure to Persistent Chemicals
Indicator #4177

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Primary Factors Determining Status and Trend: **At present, no routine Great Lakes human biomonitoring programs exist to monitor biological markers of human exposure to persistent chemicals. Individual epidemiological studies have been conducted or are on going in the Great Lakes to monitor specific populations. For this reason, the status is mixed and no trends can be determined regarding biological markers of human exposure.**

Lake-by-Lake Assessment No lake by lake assessments can be determined for this indicator. Instead, a list of ongoing research funded by ATSDR's Great Lakes Human Health Effects Research Program is provided according to the institution conducting the research.

Lake Superior

Status: Mixed
Trend: Undetermined
Primary Factors Determining Status and Trend: No ATSDR studies are currently being funded by any institution in the Lake Superior basin. However, basin wide studies do incorporate Lake Superior information.

Lake Michigan

Status: Mixed
Trend: Undetermined
Primary Factors Determining Status and Trend:
- Health Effects of PCB Exposure from Contaminated Fish (Susan L. Schantz, PhD University of Illinois at Urbana-Champaign)
- Organo-chlorides and Sex Steroids in two Michigan Cohorts (Janet Osuch, M.D., Michigan State University)
- A Pilot Program to Educate Vulnerable Populations about Fish Advisories in Upper Peninsula of Michigan (Rick Haverkate, MPH, Inter-Tribal Council of Michigan, Inc.

Lake Huron

Status: Mixed
Trend: Undetermined
Primary Factors Determining Status and Trend: No ATSDR studies are currently being funded by any institution in the Lake Huron basin. However, basin wide studies do incorporate Lake Huron information.

Lake Erie

Status: Mixed
Trend: Undetermined
Primary Factors Determining: No ATSDR studies are currently being funded by any institution in the Lake Erie basin. However, basin wide studies do incorporate Lake Erie

Status and Trend information.

Lake Ontario

Status: Mixed
Trend: Undetermined
Primary Factors Determining Status and Trend
- Neuropsychological and Thyroid Effects of PDBEs (Edward Fitzgerald, PhD, State University of New York at Albany)
- PCB Congener and Metabolite Patterns in Adult Mohawks: Biomarkers of Exposure and Individual Toxicokinetics (Anthony DeCaprio, PhD State University of New York at Albany)
- Neurobehavioral Effects of Environmental Toxics - Oswego Children's Study: Prenatal PCB Exposure and Cognitive Development (Paul Stewart, PhD., State University of New York at Oswego)

Purpose

•To assess the levels of persistent toxic substances such as methyl mercury, polychlorinated biphenyls (PCBs), and dichlorodiphenyl dichloroethenes (DDEs) in the human tissue of citizens of the Great Lakes basin; and
•To infer the efficacy of policies and technology to reduce these persistent bioaccumulating toxic chemicals in the Great Lakes ecosystem.

Ecosystem Objective

Citizens of the Great Lakes basin should be safe from exposure to harmful bioaccumulating toxic chemicals found in the environment. Data on the status and trends of these chemicals should be gathered to help understand how human health is affected by multimedia exposure and the interactive effects of toxic substances. Collection of such data supports the requirement of the Great Lakes Water Quality Agreement Annex 1 (Specific Objectives), Annex 12 (Persistent Toxic Substances), and Annex 17 (Research and Development).

State of the Ecosystem

Women and Infant Child Study

Data presented for this indicator are solely based upon one biomonitoring study that Wisconsin Department of Public Health (WiDPH) conducted in the basin. However, information on previous biomonitoring studies has been collected and is highlighted as a way to support the results of the WiDPH study and to illustrate previous and other ongoing efforts.

In the study conducted by WiDPH, the level of bioaccumulating toxic chemicals was analyzed in women of childbearing age 18 – 45 years of age. Hair and blood samples were collected from women who visited one of six participating Women Infant and Child (WIC) clinics located along Lake Michigan and Lake Superior. Levels of mercury were measured in hair samples, and mercury, PCBs, and DDEs were measured in blood serum. Awareness of fish consumption advisories was assessed through a survey.

There was greater awareness of fish consumption advisories in households in which someone fished compared to those in which no one did (Figure 1), and there was greater awareness of advisories from individuals with at least a high school education compared to those with only some high school or less education (Figure 2). More women in the 36-45 age category were aware of advisories than those of other ages, but there was less than 50% awareness in all age classes (Figure 3). More Asian women were aware of advisories that those of other races, and Hispanic women were least aware of the advisories (Figure 4).

Sixty-five hair samples were analyzed for mercury levels. The average mercury concentration in hair from fish-eating women was greater than that from non-fish eaters, ranging from 128% increase in women who ate few fish meals to 443% increase in those who ate several meals of sport-caught fish (Table 1).

Five samples of blood were drawn and analyzed for PCBs, DDEs and mercury levels. Although the small sample precludes definitive findings, the woman consuming the most fish (at least 1 sport-caught fish meal per week) had the highest concentration of DDE and the only positive finding of PCB in her serum. The woman consuming the fewest fish per year (6 – 18 fish meals) had the lowest concentration of DDE in her serum, and no PCBs were detected (Table 2).

Effects on Aboriginals of the Great Lakes (EAGLE) Project
A similar study was conducted by a partnership between the Assembly of First Nations, Health Canada and First Nations in the Great Lakes basin between 1990 and 2000 to examine the effects of contaminants on the health of the Great Lakes Aboriginal population. The Contaminants in Human Tissues Program (CHT), a major component of the EAGLE Project, identified three main goals: To determine the levels of environmental contaminants in the tissues of First Nations people in the Great Lakes basin; To correlate these levels with freshwater fish and wild game consumption; and, To provide information and advice to First Nations people on the levels of environmental contaminants found in their tissues.

The EAGLE project also analyzed hair samples for levels of mercury and blood serum for levels of PCBs and DDEs. A survey was also used to identify frequency of fish and wildlife consumption. However, the EAGLE project analyzed both male and female voluntary participants from 26 First Nations in the Great Lakes basin. The participants were volunteers, not selected on a random basis, and the project did not specifically target only fish eaters.

Key findings of the study included:
•Males consumed more fish than females and carried greater contaminant levels;
•No significant relationship was found between total fish or wild game consumption and the contaminant levels in the body;
•Levels of mercury in hair from First Nations people in the Canadian portion of the Great Lakes basin suggest the levels have decreased since 1970;
•PCBs and DDE were the most frequently appearing contaminants in the serum samples;
•Increased age of participants correlated with increased contaminant concentrations;
•Mean levels of PCBs reported in the EAGLE CHT Program were lower than or within the similar range of PCBs in fish-eaters in other Canadian health studies (Great Lakes, Lake Michigan, and St. Lawrence);
•Most people have levels of contaminants that were within Health Canada’s guidelines for PCBs in serum and mercury in hair;
•Levels of DDE were similar to levels found in other Canadian health studies; and
•There was little difference between serum levels of DDE in male and female participants.

ATSDR-sponsored Studies

The Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Environmental Protection Agency (USEPA) established the Great Lakes Human Health Effects Research Program through legislative mandate in September 1992 to "assess the adverse effects of water pollutants in the Great Lakes system on the health of persons in the Great Lakes States" (ATSDR, http://www.atsdr.cdc.gov/grtlakes/historical-background.html). This program assesses critical pollutants of concern, identifies vulnerable and sensitive populations, prioritizes areas of research, and funds research projects. Results from several recent Great Lakes biomonitoring research projects are summarized here.

Data collected from 1980 to 1995 from Great Lakes sport fish eaters showed a decline in serum PCB levels from a mean of 24 parts per billion (ppb) in 1980 to 12 ppb in 1995. This decline was associated with an 83% decrease in the number of fish meals consumed (Tee et al. 2003).

A large number of infants (2716) born between 1986 and 1991 to participants of the New York State Angler Cohort Study were studied with respect to duration of maternal consumption of contaminated fish and potential effects on gestational age and birth size. The data indicated no significant correlations gestational age or birth size in these infants and their mother's lifetime consumption of fish. The researchers noted that biological determinants such as parity, and placental infarction and maternal smoking were significant determinants of birth size (Buck et al. 2003).

The relationship between prenatal exposure to PCBs and methylmercury and performance on the McCarthy Scales of Children's Abilities was assessed in 212 children. Negative associations between prenatal exposure to methylmercury and McCarthy performance were found in subjects with higher levels of prenatal PCB exposure at 38 months. However, no relationship between PCBs and methylmercury and McCarthy performance was observed when the children were reassessed at 54 months. These results partially replicated the findings of others and suggest that functional recovery may occur. The researchers concluded that the interaction between PCBs and methylmercury can not be considered conclusive until it has been replicated in subsequent investigations (Steward et al. 2003b).

Response inhibition in preschool children exposed parentally to PCBs may be due to incomplete development of their nervous system. One hundred and eighty-nine children in the Oswego study were tested using a continuous performance test. The researchers measured the splenium of the corpus callosum, a pathway in the brain implicated in the regulation of response inhibition, in these children by magnetic resonance imaging. The results indicated the smaller the splenium, the larger the association between PCBs and the increased number of errors the children made on the continuous performance test. The researchers suggest if the association between PCBs and response inhibition is indeed causal, then children with suboptimal development of the splenium may be particularly vulnerable to these effects (Stewart et al. 2003a).

Long term consumption of fish, even at low levels, contributes significantly to body burden levels (Bloom et al. 2005).

•American Indians were assessed for their exposure to PCBs via fish consumption by analysis of blood samples and the Caffeine Breath Test (CBT). Serum levels of PCB congers #153, #170 and #180 were significantly correlated with CBT values. CBT values may be a marker for early biological effects of exposure to PCBs (Fitzgerald et al. 2005).

•Maternal exposure via fish consumption to dichlorodiphenyl dichloroethylene (DDE) and PCBs indicated that only DDE was associated with reduced birth weight in infants (Weisskopf et al. 2005).

•The association between maternal fish consumption and the risk of major birth defects among infants was assessed in the New York State Angler Cohort Study. The results indicated mothers who consumed 2 or more fish meals per month had a significantly elevated risk for male children being born with a birth defect (males: Odds Ratio = 3.01, in comparison to female children: Odds Ratio = 0.73) (Mendola et al. 2005).

Pressures

Contaminants of emerging concern, such as certain brominated flame-retardants, are increasing in the environment and may have negative health impacts. According to a recent study conducted by Environment Canada, worldwide exposure to polybrominated diphenyl ethers (PBDEs, penta) is highest in North America with lesser amounts in Europe and Asia. Food consumption is a significant vector for PBDE exposure in addition to other sources. The survey analyzed PBDE concentration in human milk by region in Canada in 1992 and in 2002 and showed a tenfold increase in concentration in Ontario (Ryan 2004).

The health effects of contaminants such as endocrine disruptors are somewhat understood. However, there is little known about the synergistic or additive effects of bioaccumulating toxic chemicals. Additional information about toxicity and interactions of a larger suite of chemicals, with special attention paid to how bioaccumulating toxic chemicals work in concert, is needed to better assess threats to human health from contaminants in the Great Lakes basin ecosystem. ATSDR has developed 5 interaction toxicological profiles for mixtures of Volatile Organic Compounds, metals, pesticides and for contaminants found in breast milk and fish.

Management Implications

There have been many small-scale studies regarding human biomarkers and bioaccumulating toxic chemicals. However, to this date, there have been no large-scale or basin-wide studies that can provide a larger picture of the issues facing the citizens of the basin. It is important that those in management positions in Federal, State, Provincial, and Tribal governments and universities foster cooperation and collaboration to identify gaps in existing biomonitoring data and to implement larger, basin-wide monitoring efforts. A Great Lakes environmental health tracking program, similar to the Center for Disease Control (CDC) Environmental Health Tracking Program, should be established by key Great Lakes partners.

Comments from the author(s)

A region-specific biomonitoring program, similar to the CDC's National Health and Nutrition Examination Survey (NHANES) project could provide needed biomonitoring information and fill in data gaps.

It is important that additional studies assessing the levels of bioaccumulative toxic chemicals through biomarkers be conducted on a much larger scale throughout the basin. In order to build up on the WIC study it would be important for a question about fish consumption from restaurants be included in future surveys. Because all states have WIC clinics, or something similar, the WiDPH monitoring tool could be implemented basin-wide.

In the future, ATSDR's Great Lakes Human Health Effects Research Program plans to continue to provide research findings to public health officials to improve their ability to assess and evaluate chemical exposure in vulnerable populations. ATSDR also plans to focus on research priorities of children's health, endocrine disruptors, mixtures, surveillance, and identification of biomarkers, i.e., exposure, effect, and susceptibility. In addition, the program will use established cohorts to monitor changes in body burdens of persistent toxic substances and specified health outcomes, and develop and evaluate new health promotion strategies and risk communication tools.

Acknowledgments
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Fish meals/3 months Sport-caught (Y/N)	Min (UG/G)	Ave (UG/G)	Max (UG/G)	N	Ave no. fish meals
0	0.00	0.07	0.24	14	0
1-9 (N)	0.04	0.16	0.59	28	2.3
1-9 (Y)	0.03	0.30	0.99	7	2.4
10+ (N)	0.04	0.33	1.23	7	12.8
10+ (Y)	0.09	0.38	1.53	9	8.11

Table 1. Concentration of mercury in hair samples from women who consumed sport-caught or not sport-caught fish during the previous three months.
Source: Wisconsin Department of Health and Family Services

ID	Fish Meals	PCB	DDE	Mercury
100 Sheb	Commercial = 1/week Sport Caught = none	0.0	0.34	<5 mcg/L
100 Sup	Commercial = 5/month Sport Caught = 30/year	0.0	0.40	<5 mcg/L
100A GB	Commercial =<6/Year Sport Caught = 6-12/Year	0.0	0.25	<5 mcg/L
105 GB	Commercial = 1/week Sport Caught = 1/week	0.4	1.20	<5 mcg/L
101A GB	Commercial = 4/month Sport Caught = 2/month	0.0	0.49	<5 mcg/L

Table 2. Number of fish meals consumed and concentration of PCBs, DDE and mercury in blood serum of 5 women who participated in the WIC study.
Source: Wisconsin Department of Health and Family Services

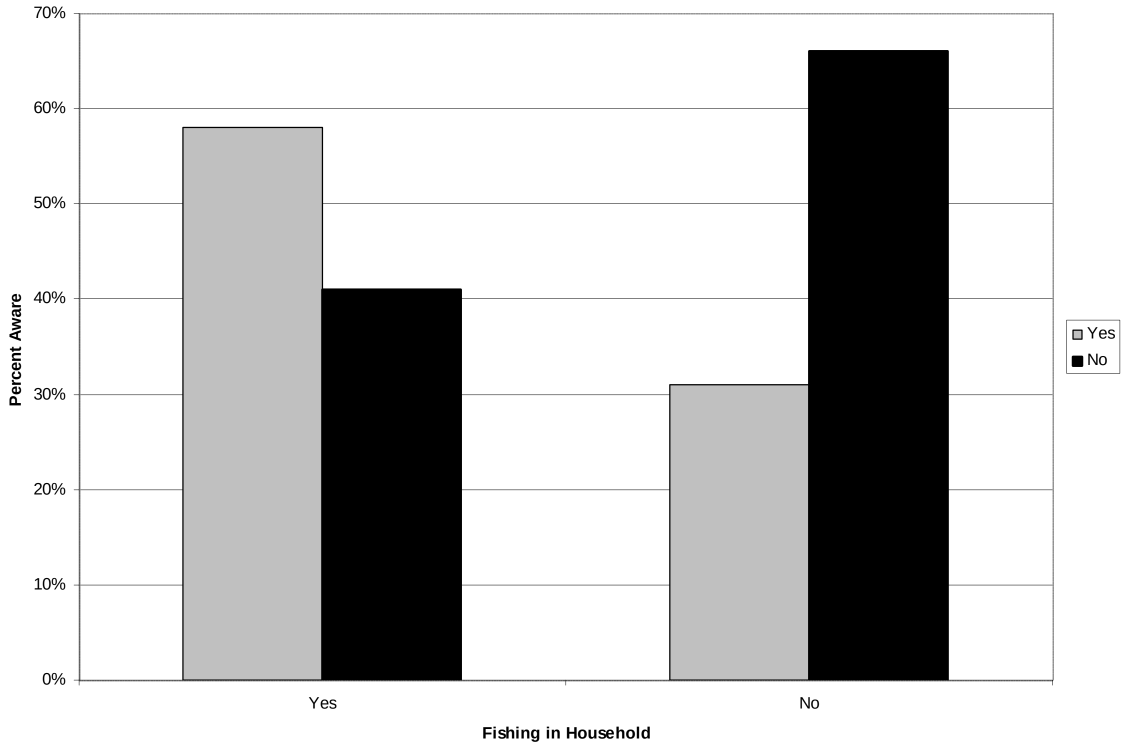

Figure 1. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories and who do (yes) or do not (no) have someone in the household who fishes**.**
Source: Wisconsin Department of Health and Family Services

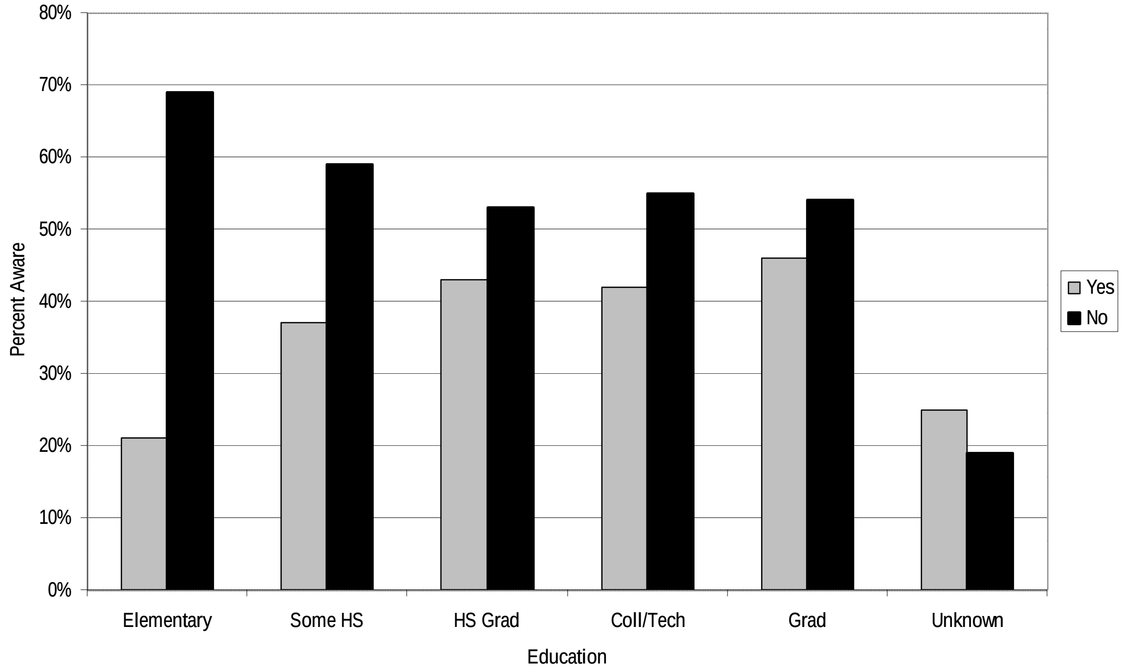

Figure 2. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to level of education.
Source: Wisconsin Department of Health and Family Services

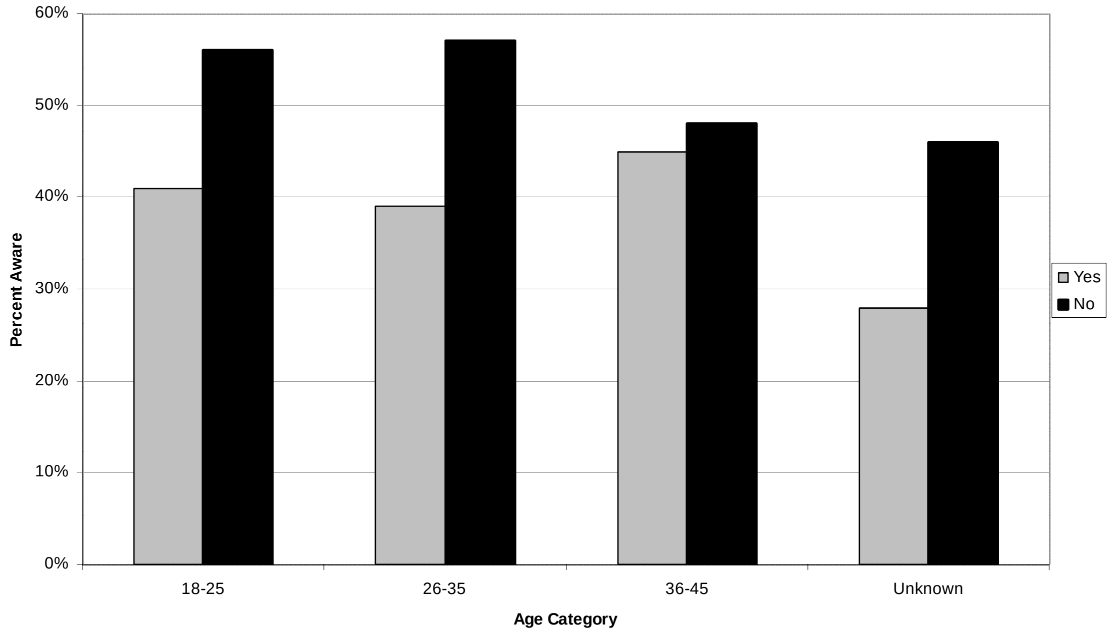

Figure 3. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to age group.
Source: Wisconsin Department of Health and Family Service

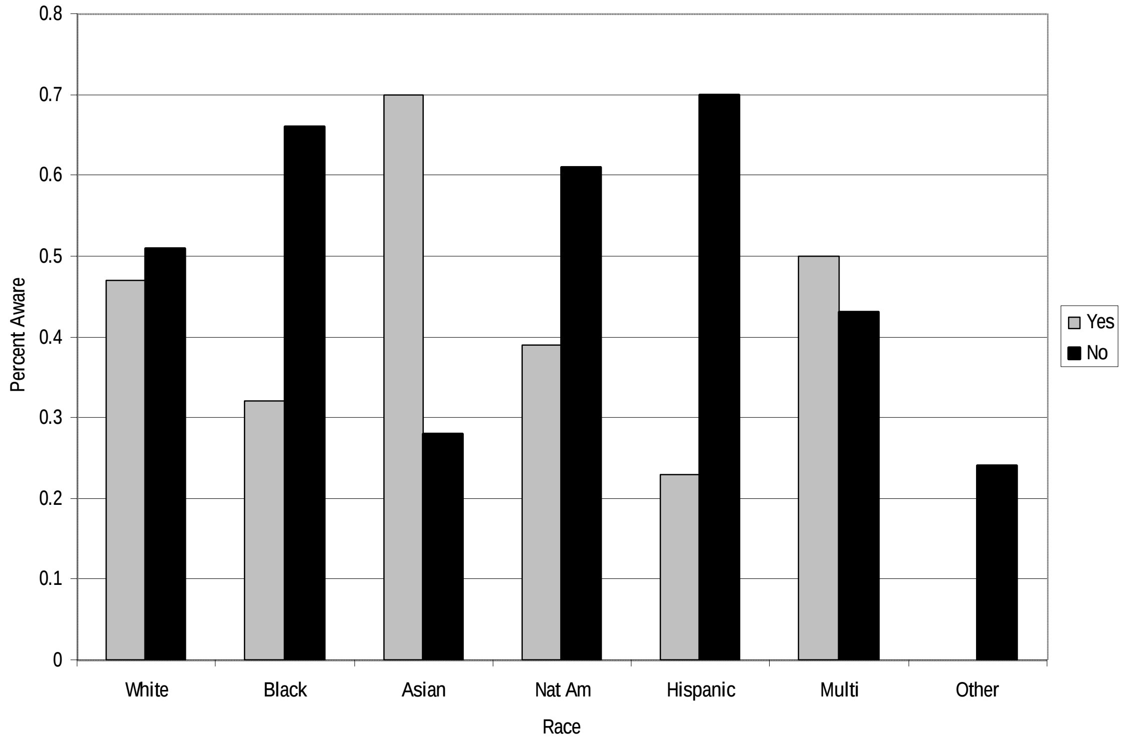

Figure 4. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to race.
Source: Wisconsin Department of Health and Family Service

Beach Advisories, Postings and Closures
Indicator #4200

*Previous beach reports for the Canadian side included inland beach data. All data for inland beaches has been removed for this 2006 report, which has skewed the results of the doughnut for previous years.

Overall Assessment

Status: **Mixed**

Trend: **Static**

Primary Factors Determining Status and Trend: While there's been an increase in monitoring and in the number of beaches reporting, the percentage of beaches open during beach season over the last 8 years remains constant in the U.S. – at roughly 70% and slightly declining conditions at 52% in Canada (see Figure 1). The percentage of beaches posted more than 10% of the beach season averaged 13% in the U.S. and 38% in Canada since 2000. The significant difference in the number of open beaches in the U.S. and Canada may be due to the difference in posting criteria. The Ontario standard is a geometric mean of 100 *E. coli* colony-forming units per 100ml of water, while in the U.S., beaches are typically posted using a single sample maximum of 235 *E. coli* cfu per 100ml.

Lake-by-Lake Assessment

Lake Superior

Status: Good

Trend: Undetermined (due to vast increase in number of reported beaches)

Primary Factors Determining Status and Trend: During 2004 and 2005, 90% or more of Lake Superior beaches (green & blue - Figure 2a) were open more than 95% of the time in the U.S. This meets the key objective of the 2002 U.S. Great Lakes Strategy goal: By 2010, 90% of monitored, high priority Great Lakes beaches will meet bacteria standards more than 95% of the swimming season. In Canada, during 2005, 5 of 9 beaches were open more than 95% of the time (green & blue - Figure 2b).

Lake Michigan

Status: Fair

Trend: Undetermined (due to vast increase in number of reported beaches)

Primary Factors Determining Status and Trend: Since 2000, on average, 77% of Lake Michigan beaches were open more than 95% of the time (green & blue - Figure 3). Increased monitoring has resulted in approximately twice as many postings since 2000 (yellow & red – Figure 3). Several groups are collaborating to identify and remediate sources of beach contamination in Lake Michigan.

Lake Huron

Status: Good

Trend: U.S.: Static; Canada: Undetermined

Primary Factors Since 1998, on average, 94% of U.S. Lake Huron beaches are open more

Determining Status and Trend	than 95% of the beach season. This meets the key objective of the 2002 U.S. Great Lakes Strategy goal. However, in Ontario, an average of 49% of Lake Huron beaches were open more than 95% during 1999 through 2005 beach seasons (green & blue – Figures 4a & 4b).

Lake Erie

Status:	Fair
Trend:	Undetermined
Primary Factors Determining Status and Trend	From 1998 to 2005, on average, 76% of U.S. Lake Erie beaches were open more than 95% of the beach season. From 1999 through 2005, in Ontario, an average of 55% of Lake Erie beaches were open more than 95% of the beach seasons (green & blue - Figures 5a & 5b). Contamination source identification work is being conducted at Lake Erie beaches.

Lake Ontario

Status:	Fair
Trend:	Undetermined
Primary Factors Determining Status and Trend	From 1998 to 2005, on average, 84% of Lake Ontario beaches in the U.S. were open more than 95% of the beach season. From 1999 through 2005, in Ontario, an average of 46% of Lake Ontario beaches were open more than 95% of the beach season (green & blue - Figures 6a & 6b).

Purpose

Assess the number of health-related swimming posting days for freshwater recreational areas (beaches) in the Great Lakes basin.

Ecosystem Objective

Waters used for recreational activities involving body contact should be substantially free from pathogens that may harm human health, including bacteria, parasites, and viruses. As the surrogate indicator, *E. coli* levels should not exceed national, state or provincial standards set for recreational waters. This indicator supports Annexes 1, 2 and 13 of the Great Lakes Water Quality Agreement (United States and Canada 1978).

State of the Ecosystem

Background

A health-related posting day is one that is based upon elevated levels of *E. coli*, or other indicator organisms, as reported by county or municipal health departments in the Great Lakes basin. *E. coli* and other indicator organisms are measured in order to infer potential harm to human health through body contact with nearshore recreational waters because they act as indicators for potential pathogens.

The Ontario provincial standard is 100 *E. coli* cfu per 100 mL, based on the geometric mean of a minimum of one sample per week from each sampling site (minimum of 5 sampling sites per beach) (Ministry of Health 1998). It is recommended by the Ontario Ministry of Health and Long-Term Care that beaches of 1000 metres of length or greater require one sampling site per 200 metres. In some cases local Health Units in Ontario have implemented a more frequent sampling procedure than is outlined by the provincial government. When *E. coli* levels exceed the limit, the beach is posted as unsafe for the health of bathers. Each beach in Ontario has a different swimming season length, although the average swimming season for Ontario beaches begins in early June and continues until the first weekend in September. The difference in the swimming season length may skew the final result of the % of beaches posted throughout the season

The bacteria criteria recommendations for *E. coli* from the U.S. Environmental Protection Agency (USEPA) are a single sample maximum value of 235 cfu per 100 ml. For enterococci, another indicator bacterium, USEPA's recommendations are a single sample maximum value of 62/100 ml (USEPA 1986). When levels of these indicator organisms exceed water quality standards, swimming at beaches is prohibited or advisories are issued to inform beachgoers that it may not be safe to swim.

One of the most important factors in nearshore recreational water quality determination is that indicator bacterial counts are at a level that is safe for bathers. Recreational waters may become contaminated with animal and human feces from sources and conditions such as combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs), malfunctioning septic systems and poor livestock management practices. This pollutant input can become further emphasized in certain areas after heavy rains. The trends provided by this indicator will aid in beach management and in the prediction of episodes of poor water quality. In addition, states, provinces, and municipalities are continuing to identify point and non-point sources of pollution at their beaches, which will determine why beach areas are becoming impaired. As some sources of contamination are identified, improved remediation measures can be taken to reduce the number of postings at beaches.

Status of Great Lakes Beach Advisories, Postings and Closures

Figure 1, shows that as the frequency of monitoring and reporting increases in the U.S. and Canada, more postings are also observed, especially after 1999. In fact, both countries experienced an approximate percentage doubling of beaches that had postings for more than 10% of the season in 2000 due to increases in monitoring and reporting. The number of U.S. beaches being included in the monitoring and reporting program in 2005 has expanded significantly (more than double since 2002) due to funding from USEPA through the BEACH Act, however, the percentage of U.S. beaches open all season and the percentage of beaches posted more than 10% of the season in 2005 are virtually unchanged when compared to 2000-2004.

While the number of beaches reporting in 2004 and 2005 in Canada decreased, the number of postings each swimming season is fairly constant at about 49% over the last 8 years, excluding 2002 and 2003 (Figure 1). Although, Lakes Ontario, Huron, and Erie have not met the key objective of the Great Lakes Strategy 2002, there are measures being taken to improve the beaches on these lakes. A new version of the Guideline for Canadian Recreational Water Quality will be out this year, focusing on implementing measures to reduce the risk of contamination (Robertson, 2006). Beach surveys, barriers, and preventive weather measures are some of the actions that will be taken to assist in improving beach quality for the Canadian Great Lakes.

U.S. beaches in Lakes Superior and Huron are meeting the key objective of the U.S. Great Lakes Strategy 2002 (http://www.epa.gov/glnpo/gls/index.html). The Great Lakes Strategy envisions that all Great Lakes beaches will be swimmable and sets a goal that by 2010, 90% of monitored, high priority Great Lakes beaches will meet bacteria standards more than 95% of the swimming season (Figures 2a & 4a - except for Lake Huron in 2002). To help meet this goal, USEPA will build local capacity in monitoring, assessment and information dissemination to help beach managers and public health officials comply with USEPA's National Beach Guidance (USEPA 2002b) at 95% of high priority coastal beaches.

Further analysis of the data may show seasonal and local trends in recreational water quality. It has been observed in the Great Lakes basin that unless contaminant sources are removed or new sources introduced, beach sample results contain similar bacteria levels after events with similar meteorological conditions (primarily wind direction and volume and duration of rainfall). If episodes of poor recreational water quality can be associated with specific events (such as meteorological events of a certain threshold), then forecasting for episodes of elevated bacterial counts may become more accurate.

Pressures

Future pressures: There may be new indicators and new detection methods available through current research efforts occurring binationally in both public and private sectors and academia. Although currently a concern in recreational waters, viruses and parasites are difficult to isolate and quantify, and feasible measurement techniques have yet to be developed. Comparisons of the frequency of beach postings are typically limited due to the use of different water quality criteria in different localities. In the U.S., all coastal states (including those along the Great Lakes) have criteria as protective as USEPA's recommended bacteriological criteria (use of *E. coli* or enterococci indicators) applied to their coastal waters. Conditions required to post Ontario beaches as unsafe have become more standardized due to the 1998 Beach Management Protocol, but the conditions required to remove the postings remain variable.

Current pressures: Additional point and non-point source pollution at coastal areas due to population growth and increased land use may result in additional beach postings, particularly during wet weather conditions. In addition, due to the nature of the laboratory analysis, each set of beach water samples requires an average of one to two days before the results are communicated to the beach manager. Therefore, a lag time in posting exists in addition to the lifting of any restrictions from the beach when safe levels are again reached. The delay in developing a rapid test protocol for *E. coli* is lending support to advanced models to predict when to post beaches.

Management Implications

Continued BEACH Act funding for beach monitoring and notification programs should be encouraged as well as funding for beach water contaminant source identification and remediation, rapid test methods research, and development of predictive models.

In Canada, a partnership between Environment Canada (Ontario Region) and the Ontario Ministry of Health and Long-Term Care have created the Seasonal Water Monitoring and Reporting System (SWMRS). This web-based application will provide local Health Units with a tool to manage beach sampling data, as well as link to the meteorological data archives of

Environment Canada. The result will be a system that potentially can be evolved to have some predictive modeling capability.

Comments from the author(s)

Wet weather sources of pollution have the potential to carry pathogenic organisms to waters used for recreation and contaminate them beyond the point of safe use. There is a need to begin identifying beach water contamination sources and implement remediation measures to reduce contaminant loading.

Many municipalities are in the process of developing long-term control plans that will result in the selection of CSO controls to meet water quality standards. The City of Toronto has an advanced Wet Weather Flow Management Master Plan, which could serve as a model to other urban areas. Information on this initiative can be obtained at: http://www.city.toronto.on.ca/wes/techservices/involved/wws/wwfmmp/index.htm.

Environment Canada (Ontario Region), in conjunction with the Ontario Ministry of Health and Long-Term Care and other potential partners, will work to implement the SWMRS reporting system. Future work will include a predictive modeling capability as well as improving the interface for public use. The system, once running, will help identify areas of chronic beach postings and, as a result, will aid in improved targeting of programs to address the sources of bacterial contamination.

Creating wetlands around rivers, or areas that are wet weather sources of pollution, may help lower the levels of bacteria that cause beaches to be posted. The wetland area may reduce high bacterial levels that are typical after storm events by detaining and treating water in surface areas rather than releasing the bacteria-rich waters into the local lakes and recreational areas. Studies by the Lake Michigan Ecological Research Station show that wetlands could lower bacterial levels at state park beaches, but more work is needed (Mitchell 2002).

Variability in the data from year to year may result due to changing seasonal weather conditions, the process of monitoring and variations in reporting, and may not be solely attributable to actual increases or decreases in levels of microbial contaminants. At this time, most of the beaches in the Great Lakes basin are monitored and have quality public notification programs in place. In addition, state beach managers are submitting their beach monitoring and advisory/closure data to the USEPA annually. The state of Michigan has an online site (http://www.glin.net/beachcast) where beach monitoring data is posted by Michigan beach managers. In Ontario, the SWMRS program will increase the efficiency and accuracy of the data collection and reporting.

To ensure accurate and timely posting of Great Lake beaches, methods must be developed to deliver quicker results that focus not just on indicator organism levels but on water quality in general. This issue is being addressed. The BEACH Act requires EPA to initiate studies for use in developing appropriate and effective indicators for improving detection in a timely manner in Coastal Recreation Waters. In connection with this requirement, the USEPA and the Centers for Disease Control and Prevention are conducting the National Epidemiological and Environmental Assessment of Recreation Waters study at various coastal freshwater and marine beaches across the country to evaluate new rapid and specific indicators of recreational water quality and to determine their relationships to health effects. Until new indicators are available, predictive models and/or the experience of knowledgeable environmental or public health officers (who regularly collect the samples) can be used on both sides of the border. Each method takes a variety of factors into account, such as amount of rainfall, cloud coverage, wind (direction and speed), current, point and non-point source pollution inputs, and the presence of wildlife, to predict whether it is likely that *E. coli* levels will likely exceed established limits in recreational waters.

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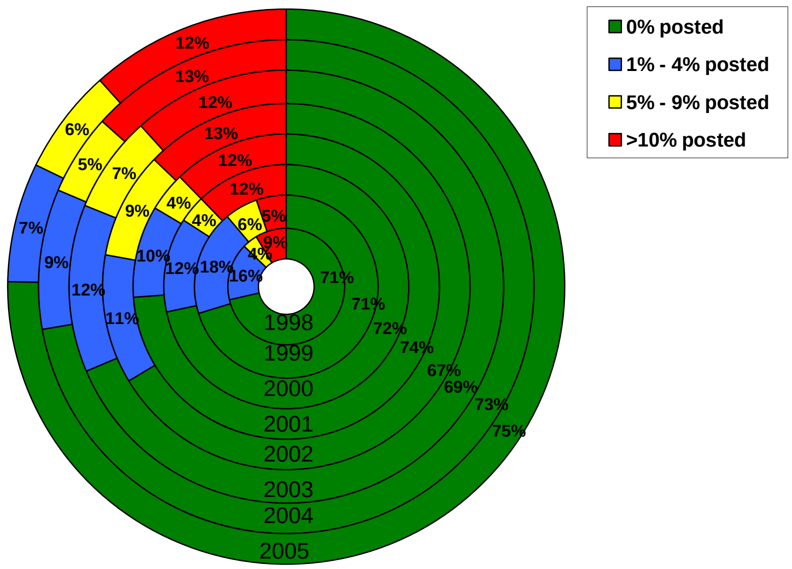
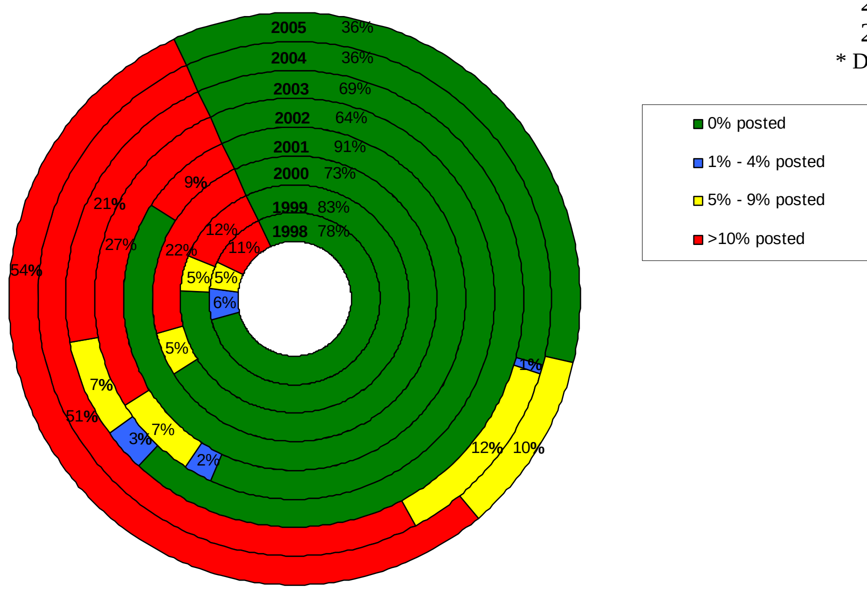
Proportion of U.S. Great Lake Basin Beaches with Postings for the 1998 - 2005 Bathing Seasons



Proportion of Canadian Great Lakes Beaches with Beach Postings for the 1998-2005 Bathing Season

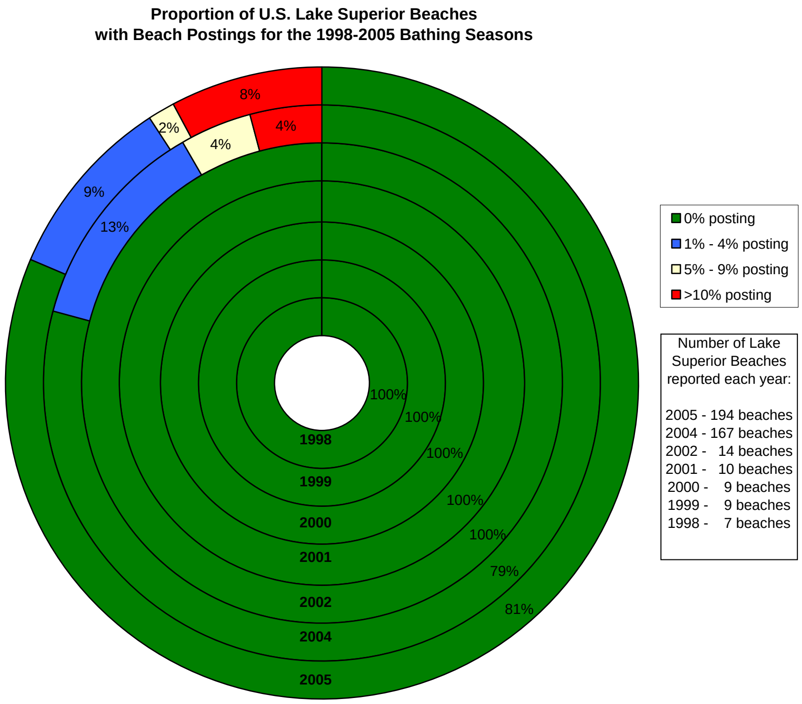


Number of Great Lake Basin Beaches reported

Canada		U.S.
194	2005	892
161	2004	787
270	2003	649 *
272	2002	381
304	2001	304
293	2000	333
238	1999	320
218	1998	303

* Data Source NRDC

Figure 1. Proportion of Great Lakes beaches with postings in the United States and Canada for the 1998-2005 bathing seasons.
Source: U.S. data: U.S. Environmental Protection Agency, Great Lakes National Programs Office and the National Resource Defense Council for 2003; Canadian data compiled by Environment Canada from Ontario Health Units



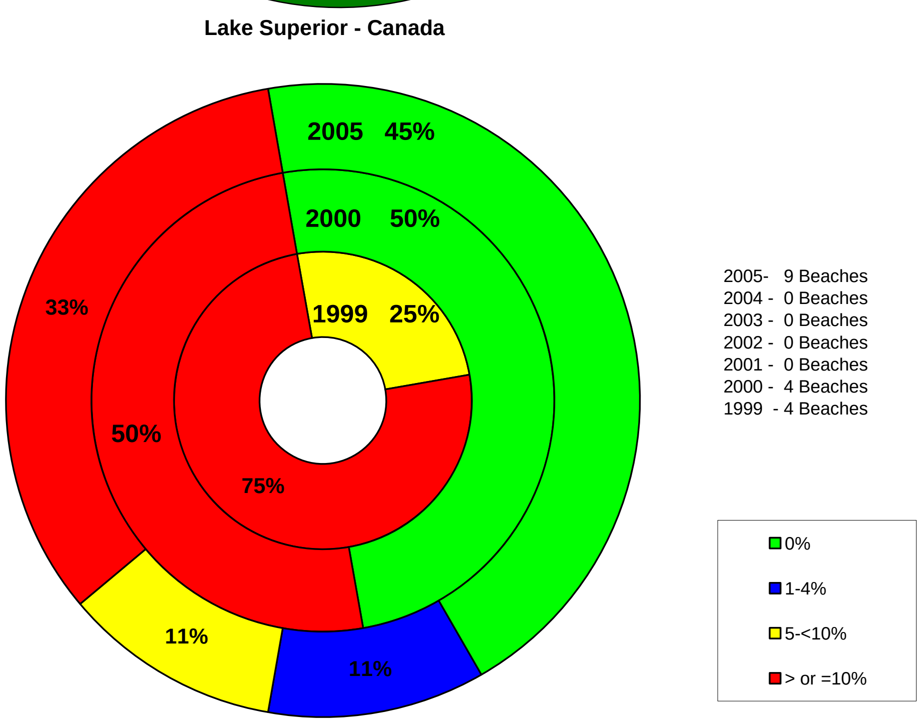


Figure 2. Proportion of Great Lakes beaches with postings for Lake Superior.
Source: U.S. data: U.S. Environmental Protection Agency, Great Lakes National Programs Office and the National Resource Defense Council for 2003; Canadian data compiled by Environment Canada from Ontario Health Units

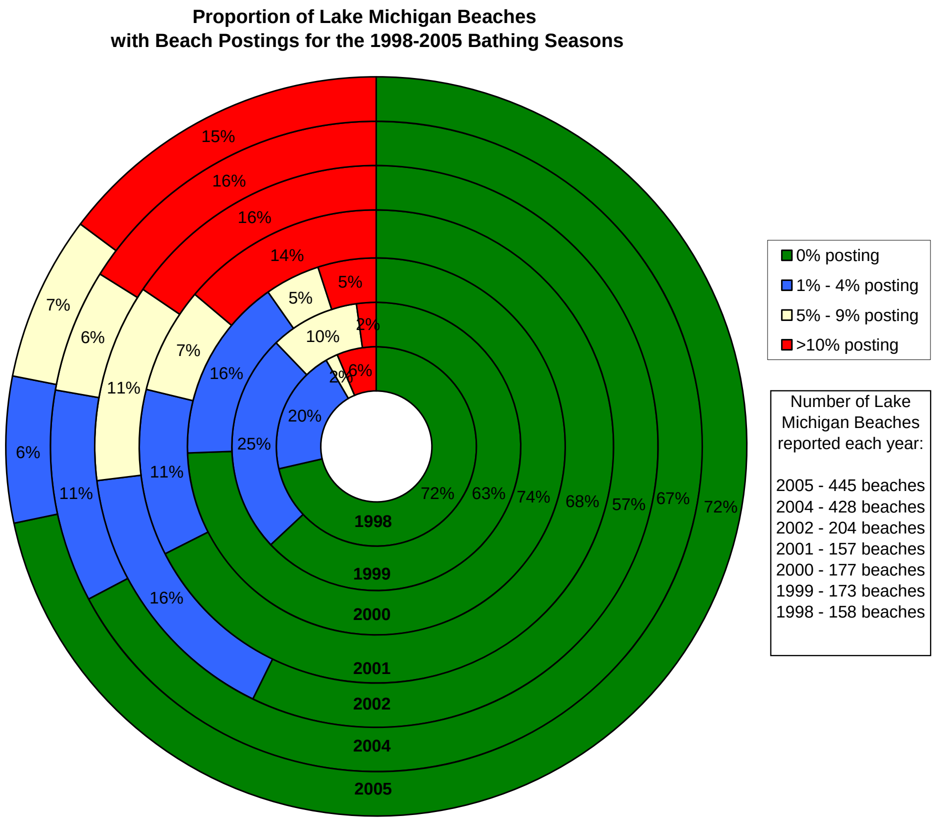
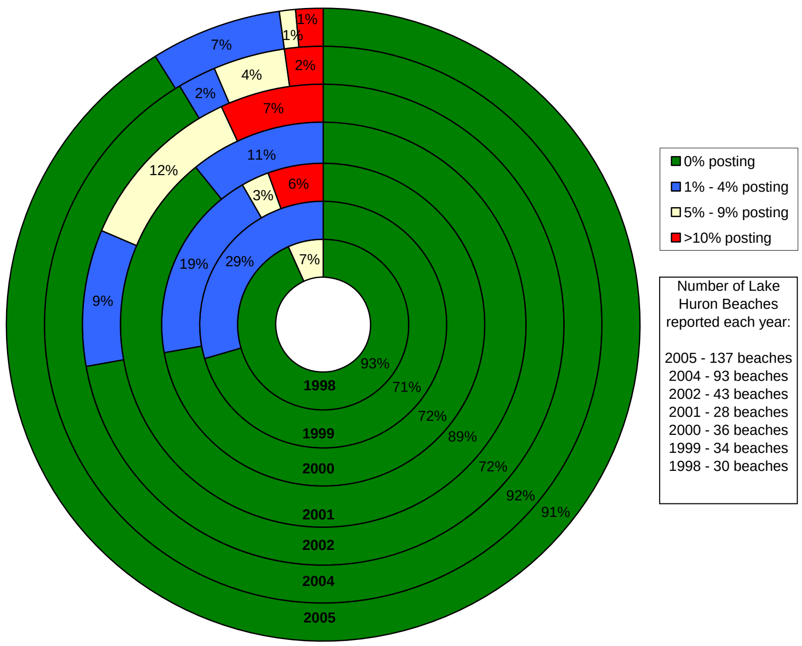


Figure 3. Proportion of Great Lakes beaches with postings for Lake Michigan.
Source: U.S. data: U.S. Environmental Protection Agency, Great Lakes National Programs Office and the National Resource Defense Council for 2003

Proportion of Lake Huron Beaches with Beach Postings for the 1998-2005 Bathing Seasons



Lake Huron - Canada

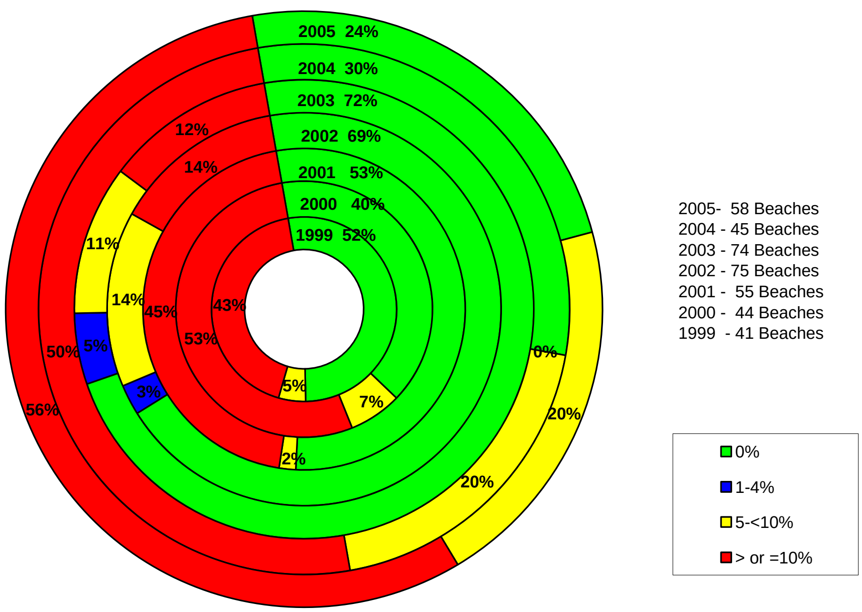
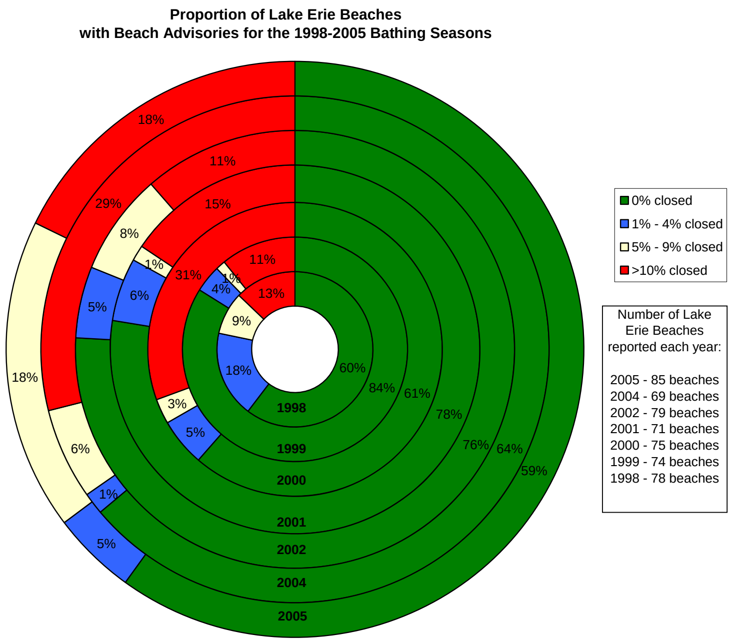


Figure 4. Proportion of Great Lakes beaches with postings for Lake Huron.
Source: U.S. data: U.S. Environmental Protection Agency, Great Lakes National Programs Office and the National Resource Defense Council for 2003; Canadian data compiled by Environment Canada from Ontario Health Units



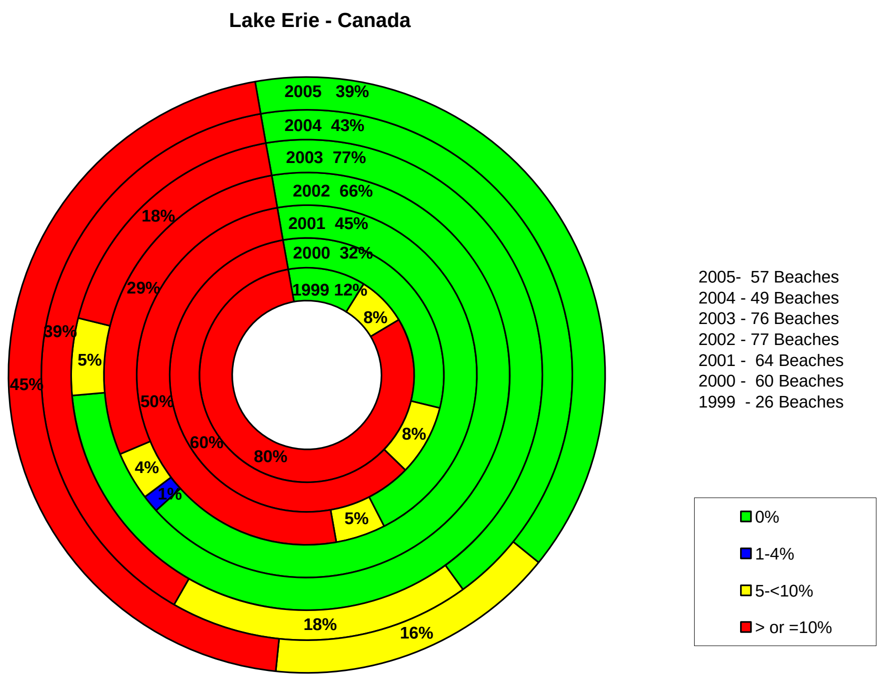
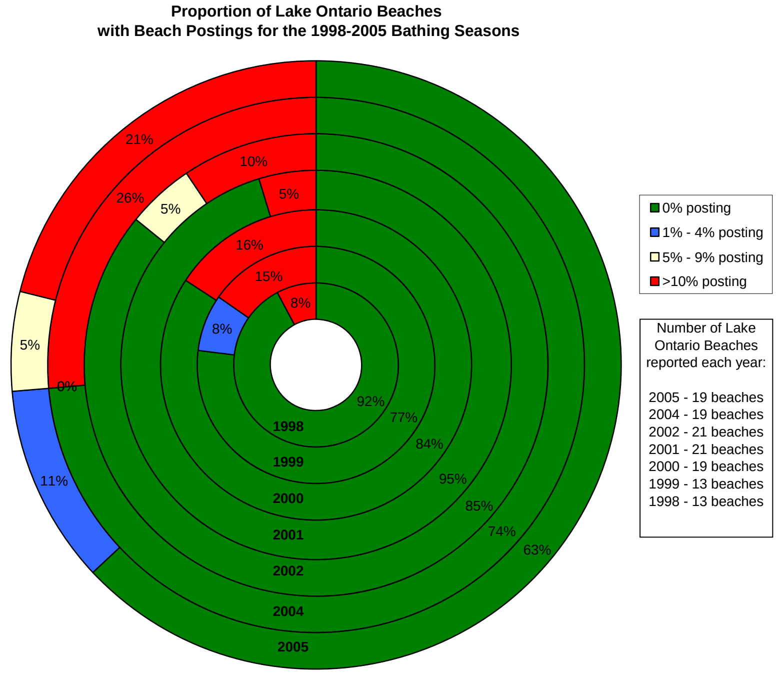


Figure 5. Proportion of Great Lakes beaches with postings for Lake Erie.
Source: U.S. data: U.S. Environmental Protection Agency, Great Lakes National Programs Office and the National Resource Defense Council for 2003; Canadian data compiled by Environment Canada from Ontario Health Units



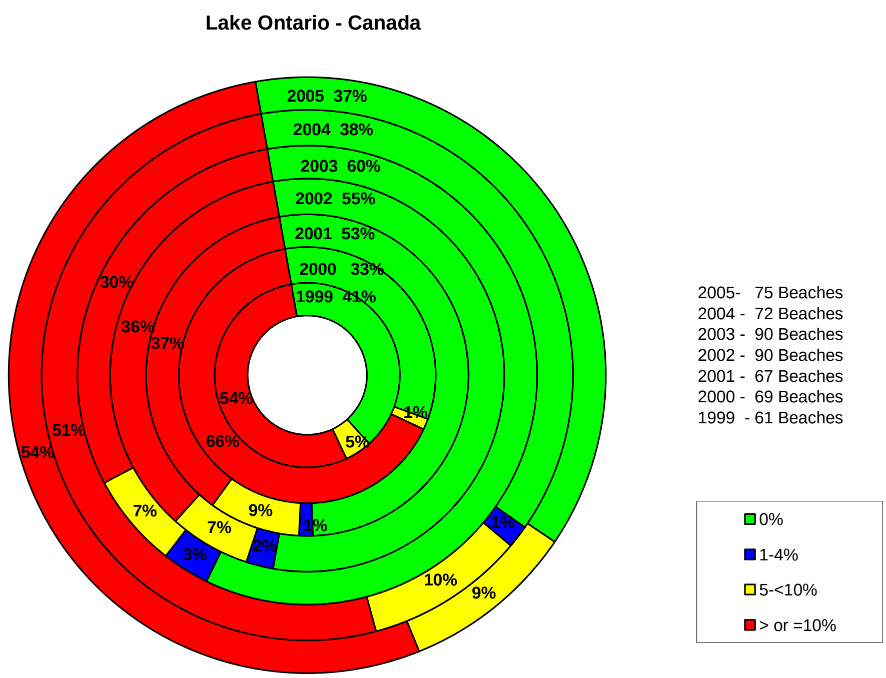


Figure 6. Proportion of Great Lakes beaches with postings for Lake Ontario.
Note: The Ontario standard is 100 *E. coli* colony-forming units per 100ml of water, while the U.S. standard is a single sample maximum of 235 *E. coli* cfu per 100ml.
Source: U.S. data: U.S. Environmental Protection Agency, Great Lakes National Programs Office and the National Resource Defense Council for 2003; Canadian data compiled by Environment Canada from Ontario Health Units

Contaminants in Sport Fish
Indicator #4201

Overall Assessment

Status: **Mixed**

Trend: **Improving**

Primary Factors Determining Status and Trend: **The Great Lakes Fish Monitoring Program (GLNPO) and the Sport Fish Contaminant Monitoring Program (Ontario Ministry of the Environment, OMOE) have been monitoring contaminant levels in Great Lakes fish for over three decades. To demonstrate trends in organic contaminant levels, average-size (60cm) lake trout were chosen by OMOE as the representative fish species due to their presence in all of the Great Lakes, their potential for exploitation by anglers and their high accumulation rates for organic contaminants. To demonstrate trends in mercury levels, average-size (45cm) walleye were chosen by OMOE due to high mercury accumulation rates. The GLNPO program was not designed to determine trends in levels of contaminants in sport fish, and it relies on individual Great Lakes States and Tribes to issue consumption advice. Rather, the GLNPO program can compare mean concentration levels to a set standard, the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory, by year. Other important differences between the GLNPO and OMOE programs include composite analysis versus individual analysis, skin on versus skin off, and whole fillet analysis versus dorsal plug analysis respectively. For this reason, only general comparisons between GLNPO and OMOE data should be made.**

Lake-by-Lake Assessment EPA – GLNPOs data can not be used for statistical trend analysis. Any trend discussions in the lake assessments below are based on OMOE data.

Contaminant concentrations for both EPA – GLNPO and OMOE can be compared to meal category advice. OMOE calculates its own advice and EPA – G LNPO compares its contaminant concentrations to the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory categories.

Lake Superior

Status: Mixed

Trend: Improving

Primary Factors Determining Status and Trend: PCB concentrations in Lake Superior lake trout have declined considerably over the period of record. In the late 1970s, PCB concentrations exceeded the current OMOE “do not eat” consumption limit. Since 1990, concentrations have generally fluctuated between 0.153 and 0.610 ppm, which would permit the consumption of 2 to 4 meals per month. Current EPA – GLNPO concentrations range between the one meal per week and the one meal per month categories.

Mercury levels in 45cm walleye from Lake Superior have ranged from 0.62 to 0.30 ppm between 1973 and 2002. With the exception of a maximum level reached in 1989 (0.84 ppm), levels of mercury in walleye have declined over the last few decades. In the last 5 years of the period of record, levels of mercury in 45cm walleye have been around 0.30 ppm, permitting the consumption of 4 meals per month for the sensitive population. These mercury levels are similar to those found in fish from other Ontario lakes and rivers.

Toxaphene has historically been high in fish from Lake Superior due to atmospheric deposition. In 60cm lake trout from Lake Superior, toxaphene has ranged from 0.810 to 0.214 ppm between 1984 and 2003. In 1993, levels of toxaphene in lake trout exceeded 1 ppm. The most current concentration is below the consumption limits and does not result in any fish consumption advisories.

Lake Michigan

Status: Mixed
Trend: Improving
Primary Factors Determining Status and Trend: EPA – GLNPO data can be used to discern general trends from Lake Michigan data due to multiple collection sites. These data display a general decline in PCB concentrations in coho and chinook salmon fillets. No OMOE samples were collected from Lake Michigan. Current EPA – GLNPO concentrations fall into the one meal per month category.

Lake Huron

Status: Mixed
Trend: Improving
Primary Factors Determining Status and Trend: PCB levels in Lake Huron OMOE lake trout declined substantially between 1976 and 2004. In 1976 concentrations exceeded 4ppm, well above the "do not eat" consumption limit of 1.22ppm for the general population. Current PCB concentrations in 60cm lake trout slightly exceed 0.153 ppm, allowing for the safe consumption of a maximum of 4 meals per month. Current EPA – GLNPO concentrations range between the one meal per week and the one meal per month categories.

Mercury levels in 45cm walleye from Lake Huron have ranged from 0.48 to 0.16 ppm between 1976 and 2004. With the exception of a maximum level reached in 1984 (0.59 ppm), there has been a general decline over the last few decades. During the last decade, levels of mercury have remained below the first level of consumption restriction (0.26ppm) for the sensitive population.

Lake Erie

Status: Mixed
Trend: Improving

Primary Factors Determining Status and Trend	Trend data are sparse for Lake Erie as lake trout are less abundant in this lake. PCB levels in OMOE fish declined between 1984 and 2003. Nevertheless, PCB concentrations in 60 cm lake trout currently restrict consumption to 2 meals per month for the general population. The sensitive population is advised not to consume these fish. Current EPA – GLNPO concentrations range between the one meal per week and the one meal per month categories. Mercury levels in 45cm walleye have declined considerably over the period of record, from 0.76 ppm in 1970 to 0.18 ppm in 2004. Over the past two decades, levels of mercury have remained between 0.10 and 0.20 ppm, and do not restrict consumption of 45cm walleye.

Lake Ontario

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	Historically, the highest concentrations of PCBs have been found in Lake Ontario. From the late 1970s to 1999, PCBs in 60 cm OMOE lake trout from Lake Ontario were at or near the "do not eat" consumption limit. Substantially lower concentrations have been found in the most recent samples in 2002 and 2004, and the current levels would permit consumption of 2 meals per month. Current EPA – GLNPO concentrations fall into the one meal per week category. Mercury levels in 45cm walleye have fluctuated between 0.23 and 0.17 ppm between 1975 and 2005. There has been no major decline in mercury concentrations in walleye, however, maximum levels have only reached 0.32ppm. Over the past 3 years, mercury concentrations in 45cm walleye have remained below the first level of consumption restriction for the sensitive population. High levels of mirex have been found in fish from Lake Ontario and it has historically been a source of fish consumption restrictions. Levels of mirex in 60cm lake trout from Lake Ontario have declined significantly from 0.302 to 0.036 ppm between 1978 and 2004, with a maximum of 0.387 ppm reached in 1985. The current concentration of mirex no longer restricts consumption of 60cm lake trout. Photomirex is a breakdown product of mirex, which also bioaccumulates in fish and has historically caused consumption restrictions in some Lake Ontario species. Levels in 60cm lake trout have declined from 0.044 to 0.015 ppm between 1994 and 2004.

Advice for the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory was calculated for sensitive populations based on a weight of evidence of non-cancer developmental effects. The general population is advised to follow the same advice based on potential cancer risk. Health Canada does not consider PCBs (especially environmental levels) to be carcinogens. Therefore, non-cancer endpoints were used to calculate the Tolerable Daily Intakes (TDI) for PCBs. This TDI was applied more-or-less equally to both sensitive and general populations. For mercury, Health Canada and US states assign separate TDIs or RfDs for the general and sensitive populations.

Purpose

•To assess potential human exposure to persistent bioaccumulative toxic (PBT) contaminants through consumption of popular sport species;
•To assess the levels of PBT contaminants in Great Lakes sport fish; and
•To identify trends over time of PBT contaminants in Great Lakes sport fish or in fish consumption advisories.

In addition to an indicator of human health, contaminants in fish are an important indicator of contaminant levels in an aquatic ecosystem because of the bioaccumulation of organochlorine chemicals in their tissues. Contaminants that are often undetectable in water can be detected in fish.

Ecosystem Objective

Great Lakes sport fish should be safe to eat and concentrations of toxic contaminants in sport fish should not pose a risk to human health. Unlimited consumption of all Great Lakes sport fish should be available to all citizens of the Great Lakes basin.

Annex 2 of the Great Lakes Water Quality Agreement (United States and Canada 1987) requires Lakewide Management Plans (LaMPs) to define "…the threat to human health posed by critical pollutants… including their contribution to the impairment of beneficial uses." Both the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory and the Guide to Eating Ontario Sport Fish are used to assess the status of the ecosystem by comparing contaminant concentrations to consumption advice.

State of the Ecosystem

Program History

Both the United States and Canada (Ontario) collect and analyze sport fish to determine contaminant concentrations, relate those concentrations to health protection values and develop consumption advice to protect human health. For U.S.-caught sport fish, the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory for PCBs is used as a standardized fish advisory benchmark for this indicator, and it is applied to historical U.S. Environmental Protection Agency (USEPA) Great Lakes National Program Office (GLNPO) data to track trends in fish consumption advice. Individual Great Lakes States and Tribes issue specific consumption advice for how much fish and which fish are safe to eat for a wide variety of contaminants. GLNPO salmon fillet data are used to demonstrate this indicator. Due to gaps and variability in GLNPO salmon fillet data, statistically significant trends are difficult to discern. For Canadian-caught sport fish, Health Canada sets Tolerable Daily Intakes (TDI) for certain contaminants of concern, including PCBs, mercury, dioxins (including dioxins, furans and dioxin-like PCBs), mirex, photomirex, toxaphene and chlordane. TDIs are defined as the quantity of a chemical that can be consumed on a daily basis, for a lifetime, with reasonable assurance that one's health will not be threatened, and they are used in the calculation of sport fish consumption limits which are listed in the Guide to Eating Ontario Sport Fish.

The GLWQA, first signed in 1972 and renewed in 1978, expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem.

Contaminants in Great Lakes Sport Fish
Since the 1970s, there have been declines in the levels of many PBT chemicals in the Great Lakes basin due to bans on the use and/or production of harmful substances and restrictions on emissions. However, because of their ability to bioaccumulate and persist in the environment, PBT chemicals continue to be a significant concern. Historically, PCBs have been the contaminant that most frequently limited the consumption of Great Lakes sport fish. In some areas, dioxins, toxaphene (Lake Superior) or mirex/photomirex (Lake Ontario) have been the consumption-limiting contaminant. Recently Health Canada has revised downward its TDIs for PCBs and dioxins, which has increased the frequency of consumption restrictions caused by PCBs and dioxins and decreased the frequency for toxaphene and mirex/photomirex.

Illustration note - Please note that differing species (coho salmon and lake trout) and units (ppm and ppb) are presented in the accompanying graphs. Typically lake trout have higher contaminant concentrations than coho salmon.

Pressures
Organochlorine contaminant levels in fish in the Great Lakes are generally decreasing. As these contaminants continue to decline, mercury will become a more important contaminant of concern in Great Lakes fish.

Concentrations of PBT contaminants such as PCBs have declined in lake trout throughout the Great Lakes basin. However, concentrations still exceed current consumption limits. Regular monitoring must continue in the Great Lakes basin to maintain trend data. In many areas of the Great Lakes, dioxins (including dioxins, furans and dioxin-like PCBs) are now the consumption-limiting contaminant and need to be monitored more frequently. The focus should also turn to PBT contaminants of emerging concern, such as brominated flame retardants, before their concentrations in sport fish reach levels that may affect human health.

Consumption advisories and PCB concentrations in coho salmon (U.S. program)
State and tribal governments provide information to consumers regarding consumption of sport caught fish. Neither the guidance nor advice of a state or tribal government is regulatory. However, some states use the federal commercial fish guidelines for the acceptable level of contaminants when giving advice for eating sport-caught fish. Consumption advice offered by most agencies is based on human health risk. This approach involves interpretation of studies on health effects from exposure to contaminants. Each state or tribe is responsible for developing fish consumption advisories for protecting the public from pollutants in fish and tailoring this advice to meet the health needs of its citizens. As a result, the advice from different states and tribal programs is sometimes somewhat different for the same lake and species within that lake.

Additional information about the toxicity of a larger suite of chemicals is needed. The health effects of multiple contaminants, including endocrine disruptors, also need to be addressed.

Management Implications
Health risk communication is a crucial component to the protection and promotion of human health in the Great Lakes. Enhanced partnerships between states and tribes involved in the issuing of fish consumption advice and USEPA headquarters will improve U.S. commercial and non-commercial fish advisory coordination. In Canada, acceptable partnerships exist between the federal and provincial agencies responsible for providing fish consumption advice to the public.

At present, PCBs and Chlordane are the only PBT chemicals that have uniform fish advisory protocols across the U.S. Great Lakes basin, mercury is being drafted. There is a need to establish additional uniform PBT advisories in order to limit confusion of the public that results from issuing varying advisories for the same species of sport fish across the basin.

In order to best protect human health, increased monitoring and reduction of PBT chemicals need to be made a priority. In particular, monitoring of contaminant levels in environmental media and biomonitoring of human tissues need to be addressed, as well as assessments of frequency and type of fish consumed. This is of particular concern in sensitive populations because contaminant levels in some fish are higher than in others. In addition, improved understanding of the potential negative health effects from exposure to PBT chemicals is needed.

In March, 2004, the U.S. Food and Drug Administration and the USEPA jointly released a consumer advisory on methylmercury in fish. The joint advisory advises women who may become pregnant, pregnant women, nursing mothers, and young children to avoid eating some types of fish and to eat fish and shellfish that are lower in mercury. While this is a step forward toward uniform advice regarding safe fish consumption, the national advisory is not consistent with some Great Lakes State's advisories. Cooperation among National, State, and Tribal governments to develop and distribute the same message regarding safe fish consumption needs to continue. Health Canada has had a similar advisory since 1999.

Comments from the author(s)
Support is needed for the States from the Great Lakes National Program Office (GLNPO) and U.S. Environmental Protection Agency (USEPA) headquarters to help facilitate a meeting to review risk assessment protocols.

Evaluation of historical long term fish contaminant monitoring data sets, which were assembled by several jurisdictions for different purposes, need to be more effectively utilized. Relationships need to be developed that allow for comparison and combined use of existing data from the various sampling programs. These data could be used in expanding this indicator to other contaminants and species and for supplementing the data used in this illustration.

Coordination of future monitoring would greatly assist the comparison of fish contaminants data among federal, provincial, state and tribal jurisdictions.

Agreement is needed on U.S. fish advisory health benchmarks for the contaminants that cause fish advisories in the Great Lakes. Suggested starting points are: The Great Lakes Protocol for PCBs and Chlordane and USEPA's reference dose for mercury. Ontario remains consistent with Health Canada's TDIs throughout the province.

Acknowledgments
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Alan Hayton, Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment, Etobicoke, ON; and

Data Sources
Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office, murphy.elizabeth@epa.gov.

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U.S. Environmental Protection Agency. 2004. Consumption Advice, Joint Federal Advisory for Mercury in Fish. http://www.epa.gov/waterscience/fishadvice/advice.html, last accessed May 24, 2004.

Data
Great Lakes Fish Monitoring Program, Great Lakes National Program Office;
Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment;
Minnesota DNR salmon fillet data for Lake Superior.

List of Tables

Table 2. Uniform Great Lakes Sport Fish Consumption Advisory.
Source: Great Lakes Sport Fish Advisory Task Force, 1993.

Table 3. Consumption limits used for the *Guide to Eating Ontario Sport Fish* (based on Health Canada TDIs).
Source: Ontario Ministry of the Environment

Last updated
SOLEC 2006

Lake	Contaminants that Fish Advisories are based on in Canada and the United States
Superior	Dioxin, PCBs, toxaphene, mercury, chlordane
Huron	Dioxin, PCBs, toxaphene, mercury, chlordane
Michigan	PCBs, mercury, dioxin, chlordane
Erie	PCBs, dioxin, mercury
Ontario	PCBs, dioxin, mercury, mirex, toxaphene

Table 1. Contaminants on which the fish advisories are based on by lake for Canada and the United States.
Source: Compiled by U.S. Environmental Protection Agency (USEPA) Great Lakes National Program Office

Consumption Advice Groups	**Concentration of PCBs (ppm)**	**Concentration of Mercury (ppm)***	**Concentration of Chlordane (ppm)****
Sensitive* and General			
Unrestricted Consumption	0 – 0.05	0 <= 0.05	0 - 0.15
2 meals/ week	NA	> 0.05 <= 0.11	NA
1 meal/ week	0.06 – 0.2	> 0.11 <= 0.22	0.16 - 0.65
1 meal/ month	0.21 – 1.0	> .22 <= 0.95	0.66 - 2.82
6 meals/ year	1.1 – 1.9	NA	2.83 - 5.62
Do not eat	>1.9	> 0.95	> 5.62

* Women of childbearing age and children under 15
**Draft Protocol for Mercury-based Fish Consumption Advice
***Discussion Paper for Chlordane HPV

Table 2. Uniform Great Lakes Sport Fish Consumption Advisory.
Source: Great Lakes Sport Fish Advisory Task Force, 1993

Advised meals per month		Concentration of PCBs (ppm)
Sensitive*	General	
8	8	< 0.153
4	4	0.153 – 0.305
Do not eat	2	0.305 – 0.610
Do not eat	1	0.610 – 1.22
Do not eat	Do not eat	>1.22

* Women of childbearing age and children under 15

Table 3. Consumption limits used for the *Guide to Eating Ontario Sport Fish* (based on Health Canada TDIs).
Source: Ontario Ministry of the Environment

Air Quality
Indicator #4202

Overall Assessment

Status: **Mixed**
Trend: **Improving**

Purpose
•To monitor the air quality in the Great Lakes ecosystem; and
•To infer the potential impact of air quality on human health in the Great Lakes basin.

Ecosystem Objective
Air should be safe to breathe. Air quality in the Great Lakes ecosystem should be protected in areas where it is relatively good, and improved in areas where it is degraded. This is consistent with ecosystem objectives being adopted by certain lakewide management plans, including Lake Superior, in fulfillment of Annex 2 of the Great Lakes Water Quality Agreement (GLWQA). This indicator also supports Annexes 1, 13, and 15.

State of the Ecosystem
Overall, there has been significant progress in improving air quality in the Great Lakes basin. For several substances of interest, both emissions and ambient concentrations have decreased over the last ten years or more. However, progress has not been uniform and differences in weather from one year to the next complicate analysis of ambient trends. Ozone and fine particulate matter can be particularly elevated during hot summers, and the trends are not consistent with those for related pollutants. Drought conditions result in more fugitive dust emissions from roads and fields, increasing the ambient levels of particulate matter.

In general, there has been significant progress with urban/local pollutants over the past decade or more, though somewhat less in recent years, with a few remaining problem districts. Ground-level ozone and fine particles remain a concern in the Great Lakes region, especially in the Detroit-Windsor region and extending northward to Sault St. Marie and eastward to Ottawa, the Lake Michigan basin, and the Buffalo-Niagara area. These pollutants continue to exceed the respective air quality criteria and standards at a number of monitoring locations in Southern Ontario and in the lower Great Lakes region in the U.S.

For the purposes of this discussion, the pollutants can be divided into urban (or local) and regional pollutants. For regional pollutants, transport is a significant issue, from hundreds of kilometers to the scale of the globe. Formation from other pollutants, both natural and man-made, can also be important. Unless otherwise stated, references to the U.S. or Canada in this discussion refer to nationwide averages.

Urban/Local Pollutants

Carbon Monoxide (CO)
Ambient Concentrations: In the U.S., CO levels for 2004 were the lowest recorded in the past 25 years. Ambient concentrations have decreased approximately 71% nationally from 1980 to 2004 and 42% nationally from 1993 to 2002. There are currently no nonattainment areas (areas where

air quality standards are not met) in the U.S. for CO. In general, CO levels have decreased at the same rate in the Great Lakes region as the nation as a whole.

In Ontario, the composite average of the one-hour maximum CO concentration decreased by 82 percent from 1971 to 2004, while the composite average of the eight-hour maximum concentration decreased 87 percent. Since 1995, average CO concentrations have only decreased 16%. Ontario has not experienced an exceedence of the 1-hour and 8-hour criteria since 1991.

Emissions: In the U.S., nationwide emissions of CO have decreased 33% from 1990 to 2002, the most recent year for which aggregate National Emissions Inventory (NEI) estimates are available. The reductions in CO emissions are almost entirely due to decreased emissions from on-road mobile sources, which have occurred despite yearly increases in vehicle miles traveled. In general, CO emissions have decreased at the same rate in the Great Lakes region as the nation as a whole.

In Canada, anthropogenic emissions (not including open sources such as forest fires) have decreased nationally by about 22% between 1990 and 2002, with a 29% decline in Ontario over the same time period. These declines are mainly the result of more stringent transportation emission standards.

Nitrogen Dioxide (NO2)

Ambient Concentrations: In Ontario, ambient average NO2 concentrations have decreased 31 % from 1975 to 2004. Over the last decade (1995 to 2004), average NO2 concentrations declined 13%. The Ontario 1-hour and 24-hour air quality criterion for NO2 were not exceeded at any of Ontario’s monitoring stations in 2004.

In the U.S., the annual mean concentrations decreased 37% from 1980 to 2004. NO2 levels in the Great Lakes region decreased at a slightly higher pace during this time period. An analysis of urban versus rural monitoring sites indicates that the declining trend seen nationwide and in the Great Lakes region can mostly be attributable to decreasing concentrations of NO2 in urban areas (similar results can be found in Ontario). There are currently no NO2 nonattainment areas in the U.S.

Emissions: In Canada, anthropogenic emissions (not including open sources such as forest fires) have increased nationally by about 5% between 1990 and 2002; however, emissions have decreased by about 11% in Ontario over the same time period. These declines are mainly the result of more stringent transportation emission standards.

In the U.S., emissions of NOx decreased by about 18% from 1990 to 2002. The downward trend can be attributed to emissions reductions at electric utilities and on-road mobile sources. Although nationwide NOx emissions have decreased, emissions from some source categories have increased including non-road engines. In general, NOx emissions have decreased at a slightly greater rate in the Great Lakes region as compared to the nation as a whole. (For more information on oxides of nitrogen, please refer to the Great Lakes Indicator Report #9000 Acid Rain.)

Sulfur Dioxide (SO2)

Ambient Concentrations: In the U.S., annual mean concentrations of SO2 decreased 54% from 1983 to 2002. From 1993 to 2002, annual mean concentrations of SO2 in the U.S. decreased 39%. The Great Lakes region experienced reducing trends on par with the national averages. Since the SOGL 2005 Report, the U.S. Environmental Protection Agency (USEPA) approved the redesignation of Lake County, Indiana, and Cuyahoga County, Ohio, to attainment areas. There are currently no nonattainment areas for SO2 in the Great Lakes region.

In Ontario, the average ambient SO2 concentrations improved 86% from 1971 to 2004, with a 17% improvement since 1995. Ontario did not experience any violations of the one-hour SO2 criterion (250 ppb), 24-hour criterion (100 ppb), or the annual criterion (20 ppb) in 2004.

Emissions: In the U.S., national SO2 emissions were reduced 33% from 1990 to 2002 mostly in response to regulations imposing cuts on coal-burning power plants. SO2 emissions in the Great Lakes region have decreased at a much greater rate than the national trend over this time period.

Canadian emissions decreased 29% nationwide from 1990 to 2002, but have remained relatively constant since 1995. Even with increasing economic activity, emissions remain about 29% below the target national emission cap. From 1990 to 2002, the emissions of SO2 in Ontario decreased 47%. These reductions mostly were the result of the Canada Acid Rain Program which primarily targeted major non-ferrous smelters and fossil fuel-burning power plants in the seven eastern-most provinces.

(For more information on sulfur dioxide, please refer to the Great Lakes Indicator Report #9000 Acid Rain.)

Lead

Ambient Concentrations: U.S. concentrations of lead decreased 97% from 1980 to 2004 with most of the reductions occurring during the 1980s and early 1990s. Lead levels in the Great Lakes region decreased at nearly the same rate as the national trend over this time. There are no nonattainment areas for lead in the Great Lakes region.

Based on historical data, lead concentrations at urban monitoring stations in Ontario have decreased over 95%.

Emissions: National lead emissions in the U.S. decreased 98% from 1980 to 1999 mostly as a result of regulatory efforts to reduce the content of lead in gasoline. The declines since 1990 have been from metals processing and waste management industries.

Similar improvements in Canada have followed with the usage of unleaded gasoline.

Total Reduced Sulfur (TRS)

Ambient Concentrations: This family of compounds is of concern in Canada due to odour problems in some communities, normally near industrial or pulp mill sources. Ontario did not experience any violations of the one-hour TRS criterion (27 ppb) in 2004.

Emissions: Hydrogen sulphide accounts for more than half of total reduced sulphur emissions. There is no requirement to report TRS emissions in the NPRI; however, there has been a requirement to report hydrogen sulphide emissions since 2000. Hydrogen sulphide emissions have increased about 47 percent from 2000 to 2003.

PM10

Ambient Concentrations: PM10 is the fraction of particles in the atmosphere with a diameter of 10 microns or smaller. Annual average PM10 concentrations in the U.S. have decreased 28% from 1990 to 2004. Annual average concentrations in the Great Lakes region have decreased at nearly the same rate as the national trend over this time. The national 24-hour PM10 concentration was 31% lower than the 1990 level. 24-hour average concentrations in the Great Lakes region have decreased at nearly the same rate as the national trend over this time. There are currently no nonattainment areas in the Great Lakes region. Since the SOGL 2003 report, the USEPA approved the redesignation of 2 areas in Cook County, Illinois, to attainment areas.

Canada does not have an ambient target for PM10. However, Ontario has an interim standard of 50 µg/m3 over a 24-hour sampling period to guide decision-making.

Emissions: In the U.S., national direct source man-made emissions decreased 29% from 1990 to 2002. The fuel combustion source category experienced the largest absolute decrease in emissions (422,000 tons and 35%), while the on-road vehicle sector experienced the largest relative decrease (183,000 tons and 47%). The Great Lakes region experienced reducing trends on par with the national averages.

In Canada, anthropogenic emissions (not including open sources such as road dust) have decreased nationally by about 15% between 1990 and 2002. However, total PM10 emissions including open sources such as road dust have actually increased by 34% in Canada over this time period. Ontario has experienced similar trends over this time period.

Air Toxics

This term captures a large number of pollutants that, based on the toxicity and likelihood for exposure, have the potential to harm human health (e.g. cancer causing) or adverse environmental and ecological effects. Some of these are of local importance, near to sources, while others may be transported over long distances. Monitoring is difficult and expensive, and usually limited in scope as such toxics are usually present only at trace levels. Recent efforts in Canada and the U.S. have focused on better characterization of ambient levels and minimizing emissions. In the U.S., the Clean Air Act targets a 75% reduction in cancer "incidence" and a "substantial" reduction in non-cancer risks. The Maximum Available Control Technology (MACT) program sets emissions standards on industrial sources to reduce emissions of air toxics. Once fully implemented, these standards will cut emissions of toxic air pollutants by nearly 1.36 million metric tons per year from 1990 levels.

In February 2006, EPA released the results of its national assessment of air toxics (NATA) using 1999 emissions. The purpose of the national-scale assessment is to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern in terms of contributing to population risk. From a national perspective, benzene is the most significant air toxic for which cancer risk could be estimated, contributing 25 percent of the average individual cancer risk identified in this assessment. Based on EPA's national emissions inventory, the key sources for benzene are onroad (49%) and nonroad mobile sources (19%), and open burning, prescribed fires and wildfires (14%). EPA projects that onroad and nonroad mobile source benzene emissions will decrease by about 60% between 1999 and 2020, as a result of motor vehicle standards, fuel controls, standards for nonroad engines and equipment, and motor vehicle inspection and maintenance programs.

Of the 40 air toxics showing the potential for respiratory effects, acrolein is the most significant, contributing 91 percent of the nationwide average noncancer hazard identified in this assessment. Note that the health information and exposure data for acrolein include much more uncertainty than those for benzene. Based on the national emissions inventory, the key sources for acrolein are open burning, prescribed fires and wildfires (61%), onroad (14%) and nonroad (11%) mobile sources. The apparent dominance of acrolein as a noncancer "risk driver" in both the 1996 and 1999 national-scale assessment has led to efforts to develop an effective monitoring test method for this pollutant. EPA projects that acrolein emissions from on-road sources will be reduced by 53% between 1996 and 2020 as a result of existing motor vehicle standards and fuel controls. The assessment estimates that most people have a lifetime cancer risk between 1 and 25 in a million from air toxics. This means that out of one million people, between 1 and 25 people have increased likelihood of contracting cancer as a result of breathing air toxics from outdoor sources, if they were exposed to 1999 levels over the course of their lifetime. The assessment estimates that most urban locations have air toxics lifetime cancer risk greater than 25 in a million. Risk in transportation corridors and some other locations are greater than 50 in a million. In contrast, one out of every three Americans (330,000 in a million) will contract cancer during a lifetime, when all causes (including exposure to air toxics) are taken into account. Based on these results, the risk of contracting cancer is increased less than 1% due to inhalation of air toxics from outdoor sources.

In Canada, key toxics such as benzene, mercury, dioxins, and furans are the subject of ratified and proposed new standards, and voluntary reduction efforts.

Ambient Concentrations: A National Air Toxics Trend Site (NATTS) network was launched in the U.S. in 2003 to detect trends in high-risk air toxics such as benzene, formaldehyde, 1,3-butadiene, acrolein, and chromium. There are four NATTS monitoring sites in the Great Lakes region including Chicago, IL, Detroit, MI, Rochester, NY and Mayville, WI. Some ambient trends have also been found from existing monitoring networks. Average annual urban concentrations of benzene have decreased 60% in the U.S. from 1994 to 2004.

Manganese compounds are hazardous air pollutants of special concern in the Great Lakes region. They are emitted by iron and steel production plants, power plants, coke ovens, and many smaller metal processing facilities. Exposures to elevated concentrations of manganese are harmful to human health and have been associated with subtle neurological effects, such as slowed eye-hand coordination. The most recent NATA results identify manganese compounds as the largest contributor to neurological non-cancer health risk in the U.S. Modeled estimates of ambient manganese compounds in all 3222 U.S. counties show that among the 50 counties with the highest concentrations nation-wide, 20 are located in Region 5. The median average annual manganese concentration at 21 trend sites showed a 14.7% decline between 2000 and 2004. Additional years of data will be needed to confirm this apparent trend.

In Ontario, average annual urban concentrations of benzene, toluene, and xylene have decreased about 45%, 42%, and 50% respectively from 1995 to 2004.

Emissions: The Great Lakes Toxics Inventory is an ongoing initiative of the regulatory agencies in the eight Great Lakes States and the Province of Ontario. Emissions inventories have been developed for 1996, 1997, 1998, 1999, 2001, and 2002 but different approaches were used to develop these inventories making trend analysis difficult.

In Canada, emissions are also being tracked through the National Pollutant Release Inventory (NPRI). The NPRI includes information on some of the substances listed by the Accelerated Reduction/Elimination of Toxics (ARET) program. Significant voluntary reductions in toxic emissions have been reported through the ARET program.

In the U.S., emissions are also being tracked through the National Emissions Inventory (NEI) and the Toxics Release Inventory (TRI). NEI data indicate that national U.S. air toxic emissions have dropped approximately 42% between the 1990 and 2002, though emission estimates are subject to modification and the trends are different for different compounds. The 1999 NEI also showed that Region 5 had the highest manganese emissions of all EPA Regions, contributing 36.6% of all manganese compounds emitted nation-wide.

The TRI, which began in 1988, contains information on releases of nearly 650 chemicals and chemical categories from industries, including manufacturing, metal and coal mining, electric utilities, and commercial hazardous waste treatment, among others. Although the TRI has expanded and changed over the years, it is still possible to ascertain trends over time for core sets of toxics. The total reported air emissions of the TRI 1988 Core Chemicals (299 chemicals) in the eight Great Lakes states have decreased by about 78% from 1988 to 2004. According to the TRI manganese emissions from point sources declined between 1988 and 2003 both nationally (26.2%) and in Region 5 (36.7%). Year-to-year variability in manganese emissions is high, however, and recent emissions data (1996-2003) suggest a weaker trend: emissions dropped 7.6% and 12.4% nation-wide and in Region 5, respectively.

Regional Pollutants

<u>Ground-Level Ozone (O3)</u>

Ozone is generally considered a secondary pollutant, which forms from reactions of precursors (VOCs - volatile organic compounds and NOx - nitrogen oxides) in the presence of heat and sunlight. Ozone is a problem pollutant over broad areas of the Great Lakes region, except for the Lake Superior basin. Local onshore circulations around the Great Lakes can exacerbate the problem, as pollutants can remain trapped for days below the maritime/marine inversion (this forms when a layer of warm air moves to lie over colder marine air, thus trapping the colder air). Consistently high levels are found in provincial parks near Lakes Huron and Erie, and western Michigan is impacted by transport across Lake Michigan from Chicago.

Ambient Concentrations: In 2004, ozone levels in the U.S. showed continued improvement. National assessments find some uneven improvement in peak levels, but with indications that average levels may be increasing on a global scale. Ozone levels are still decreasing nationwide, but the rate of decrease for 8-hour ozone levels has slowed since 1990. The Great Lakes region has experienced smaller decreases than nationwide averages (Figure 1). Many of the improvements in ozone concentrations during these times have been a result of local emission reductions in urban areas.

To address the regional transport of ozone and ozone-forming pollutants in the eastern half of the country, the U.S. EPA developed a program to reduce regional NOx emissions called the NOx State Implementation Plan (SIP) Call in 2002. An analysis of 2002-2004 ozone data show that the NOx SIP Call achieved an additional 4 percent reduction in seasonal 8-hour ozone concentrations. It is important to note that weather conditions in 2004 were not conducive to ozone formation, and that ozone levels in 2005 and 2006 could be higher than in 2004 depending on weather conditions. The NOx SIP Call also appears to have caused a gradual decline in 8-hour daily maximum ozone concentrations (Figure 2).

Since the SOGL 2005 Indicator Report, the 1-hour ozone standard was revoked in the U.S. and all 6 nonattainment areas in the Great Lakes basin were reclassified. Now there are 28 areas covering 70 counties in the Great Lakes basin designated as nonattainment for the 8-hour ozone standard (Chicago-Gary-Lake Co, IL-IN metropolitan area; South Bend/Elkhart, IN; LaPorte County, IN; Fort Wayne, IN; Detroit-Ann Arbor metro area, MI; Flint metro area, MI; Grand Rapids metro area, MI; Muskegon County, MI; Allegan County, MI; Huron County, MI; Kalamazoo-Battle Creek metro area, MI; Lansing-East Lansing metro area, MI; Benton Harbor area, MI; Benzie County, MI; Cass County, MI; Mason County, MI; Jamestown, NY; Buffalo-Niagara Falls metro area, NY; Rochester metro area, NY; Jefferson County, NY; Toledo metro area, OH; Cleveland-Akron-Lorain metro area, OH; Erie, PA; Milwaukee-Racine metropolitan area, WI; Sheboygan County, WI; Manitowoc County, WI; Kewaunee County, WI; and Door County, WI).

In Ontario, ozone concentrations continued to exceed Ontario's Ambient Air Quality Criterion (AAQC). In 2004, 28 of the 37 ambient Air Quality Index (AQI) monitoring stations in Ontario recorded exceedences of the 1-hour ozone AAQC on at least one occasion. Although the ozone levels continue to exceed Ontario's AAQC, the 1-hour maximum ozone concentrations recorded in Ontario have, on average, decreased by 13% from 1980 to 2004. Over the past 10 years (1995 to 2004), the annual composite means of one-hour ozone maximum concentrations have decreased by about 4%. In fact, the year 2004 recorded the lowest one-hour ozone maximum (84 ppb) over the last 25 years. This is partly related to the lack of weather conditions conducive to formation of ground-level ozone in 2004; however, it also indicates that many of the efforts to curb emissions and improve the air quality in Ontario are working.

However, Ontario has experienced an overall increasing trend in seasonal mean ozone concentrations over the same 25-year period. The summer and winter seasonal ozone means have increased by approximately 25% and 44%, respectively (Figure 3). The increase of the summer mean is related to meteorological conditions and the transport of ozone and its precursors into Ontario, whereas the increase of the winter mean indicates an increase in background concentrations of ozone throughout Ontario. Similar increases in the background concentrations of ozone have been found in other parts of North America.

Although Ontario is not required to report on the new Canada-wide Standard (CWS) for ozone until 2006, data from 2002-2004 indicate that all but one monitoring site (Thunder Bay) in Ontario exceeded the ozone CWS of 65 ppb based on the 4^{th} highest ozone eight-hour running average over three consecutive years.

Emissions: In the U.S., VOC emissions from anthropogenic sources decreased 32% from 1990 to 2002. The rate of reduction in the Great Lakes basin was slightly less than the national average. In 2002, VOC emissions from biogenic sources were estimated to determine the relative contribution of natural versus anthropogenic sources. It was estimated that biogenic emissions contributed approximately 71% of all VOC emissions in the country. NOx emissions in the U.S. have also decreased 18% from 1990 to 2002.

In Ontario, man-made VOC emissions have decreased about 27 percent from 1990 to 2002. The reductions are mostly attributable to the transportation and petroleum refining sectors. VOC emissions in all of Canada have decreased 22 % over the same time period. Canadian NOx emissions have increased nationally by about 5% between 1990 and 2002; however, emissions have decreased by about 11% in Ontario over the same time period.

$PM_{2.5}$

This fraction of particulate matter (diameter of 2.5 microns or less) is a health concern because it can penetrate deeply into the lung, in contrast to larger particles. $PM_{2.5}$ is primarily a secondary pollutant produced from both natural and man-made precursors (SO2, NOX, and ammonia).

Ambient Concentrations: A CWS for $PM_{2.5}$ of 30 µg/m3 was established in June 2000. Achievement of the standard is based on the 3-year average of the annual 98th percentiles of the daily, 24-hour (midnight to midnight) average concentrations. As $PM_{2.5}$ monitoring has only begun quite recently, there is not enough data to show any national long-term trends. Although Ontario is not required to meet the CWS for fine particulate matter until 2010 and begin reporting on progress towards meeting the new CWS until 2006, data from 2004 indicate that many areas in Ontario have recorded 98^{th} percentile daily averages of $PM_{2.5}$ above 30 ug/m3 (Figure 4). In Ontario, during summer episodes, PM2.5 mainly consists of sulphate particles.

In the U.S., annual average $PM_{2.5}$ concentrations in 2004 were the lowest since nationwide monitoring began in 1999. The trend is based on measurements collected at 707 monitoring stations that have sufficient data to assess trends over that period. Concentrations in 2004 represent an 11% decrease since 1999. The Great Lakes region has experienced a slightly greater decline than the national average. In 2004, the average 24-hour $PM_{2.5}$ concentration was also 11% lower than the average 1999 level. 24-hour $PM_{2.5}$ concentrations in the Great Lakes region decreased at nearly the same rate as the national trend over this time. Despite some uncertainties, the reductions in PM2.5 concentrations in the Great Lakes region appear to be largely a result of emission reduction at sources that contribute to the formation of carbon-containing particles (Figure 5). Direct emissions of carbon-containing particles include motor vehicles and fuel combustion.

There are three areas in the Great Lakes region that are designated nonattainment for the PM2.5 standard (Chicago-Gary-Lake Co, IL-IN metropolitan area; Detroit-Ann Arbor, MI metro area; and the Cleveland-Akron-Lorain, OH metro area).

Emissions: In the U.S., direct emissions from anthropogenic sources decreased 27 percent nationally between 1990 and 2002; however, this decreasing trend does not account for the formation of secondary particles. The largest absolute reduction in PM2.5 emissions was seen in the fuel combustion source category (347,000 tons and 38%); while, the largest relative reduction in PM2.5 emissions was in the on-road vehicle category (175,000 tons and 54%).

In Canada, emissions (not including open sources such as road dust, construction operations, and forest fires) have decreased nationally by about 14% between 1990 and 2002. However, total PM2.5 emissions including open sources have increased by 6% in Canada over this time period. Ontario has experienced similar trends over this time period.

Pressures

Continued economic growth, population growth, and associated urban sprawl are threatening to offset emission reductions achieved by policies currently in place, through both increased energy consumption and vehicles miles traveled. The changing climate may affect the frequency of weather conditions conducive to high ambient concentrations of many pollutants. There is also increasing evidence of changes to the atmosphere as a whole. Continuing health research is both broadening the number of toxics, and producing evidence that existing standards should be lowered.

Management Implications

Major pollution reduction efforts continue in both U.S. and Canada. In Canada, new ambient standards for particulate matter and ozone have been endorsed, with a 2010 achievement date. This will involve updates at the Federal level and at the provincial level (the Clean Air Action Plan, and Ontario's Industry Emissions Reduction Plan). Toxics are also addressed at both levels. The Canadian Environmental Protection Act (CEPA) was recently amended.

In the U.S., new, more protective ambient air standards have been promulgated for ozone and particulate matter. MACT (Maximum Available Control Technology) standards continue to be promulgated for sources of toxic air pollution. USEPA has also begun looking at the risk remaining after emissions reductions for industrial sources take effect.

At the international level, Canada and the U.S. signed the Ozone Annex to the Air Quality Agreement in December 2000. The Ozone Annex commits both countries to reduce emissions of NOX and VOCs, the precursor pollutants to ground-level ozone, a major component of smog. This will help both countries attain their ozone air quality goals to protect human health and the environment. Canada estimates that total NOX reduction in the Canadian transboundary region will be between 35% and 39% of the 1990 levels by 2010. Under the Clean Air Action Plan, Ontario is also committed to reducing provincial emission of NOX and VOCs by 45% of 1990 levels by 2015, with interim targets of 25% by 2005.

The U.S. estimates that the total NOx reductions in the U.S. transboundary region will be 36% year-round by 2010 and 43% during the ozone season. Canada and the U.S. have also undertaken cooperative modeling, monitoring, and data analysis and developed a work plan to address transboundary PM issues. PM2.5 networks will continue to develop in both countries, to determine ambient levels, trends, and consequent reduction measures. Review of standards or objectives will continue to consider new information. Efforts to reduce toxic pollutants will also continue under North America Free Trade Agreement and through United Nations-Economic Commission for Europe protocols. The U.S. is continuing its deployment of a national air toxics monitoring network.

Comments from the author(s)
Updated 2005 emissions data from Canada's National Pollutant Release Inventory (NPRI) is expected to become available in the fall of 2006. Environment Canada is also expected to release a five-year comprehensive report on the progress towards the Canada-wide Standards (CWS) for PM and ozone in the fall of 2006.

These new data will be incorporated into the indicator report before finalization.

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List of Figures

Source: Figure 004-4. Ambient ozone concentrations, 1980-2004, by EPA region; 2007 Report on the Environment (ROE) Technical Document. http://www.epa.gov/indicators/, last accessed September 5, 2006.

Figure 2. Rural Seasonal Average 8-hour Maximum Ozone Concentrations by EPA Region, 1997-2004.
Source: Sidebar "Ozone Reduction in Rural Areas Shows Regional Improvements" on page 20 of U.S. Environmental Protection Agency (USEPA). 2005a. Evaluating Ozone Control Programs in the Eastern United States: Focus on the NOx Budget Trading Program, 2004. EPA454-K-05-001. http://www.epa.gov/airtrends/2005/ozonenbp/, last accessed September 5, 2006.

Figure 3. Trend of Ozone Seasonal Means at Sites Across Ontario (1980-2004).
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Figure 4. $PM_{2.5}$ Levels at Selected Sites Across Ontario, 98th Percentile PM2.5 Daily Average (2004).
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Figure 5. Trends of $PM_{2.5}$ and its chemical constituents in the Industrial Midwest of the U.S., 1999-2003.
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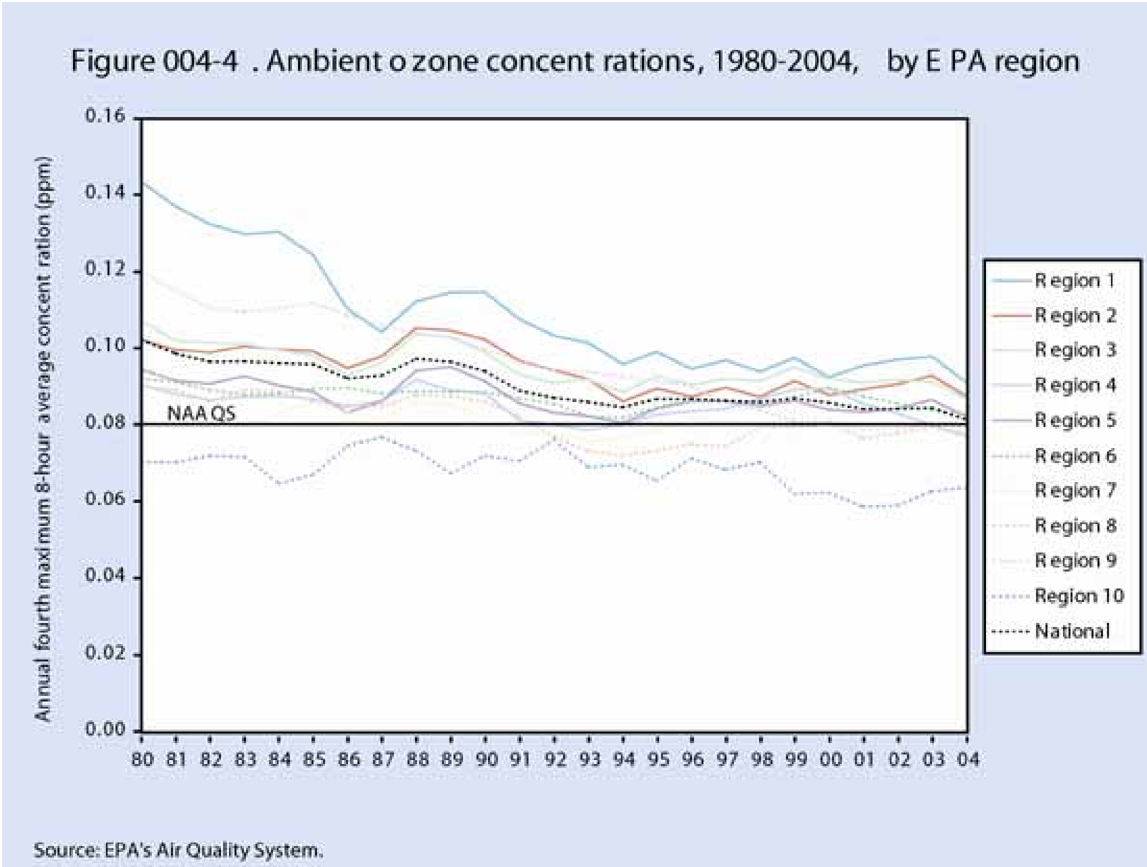

Figure 1. Trends in Fourth Highest Daily Maximum 8-hour ozone concentration (ppm) by EPA Region 1980-2004.
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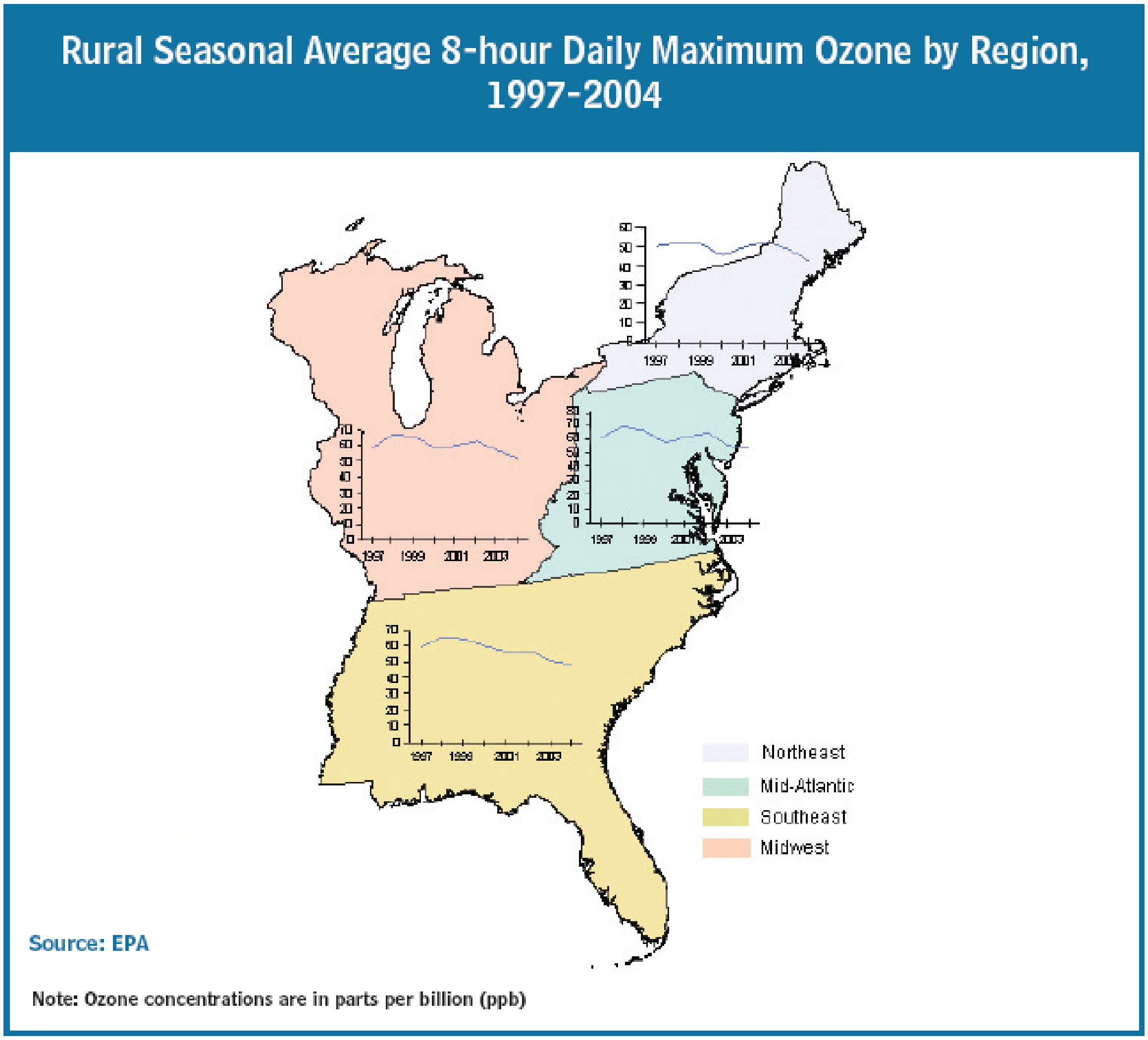

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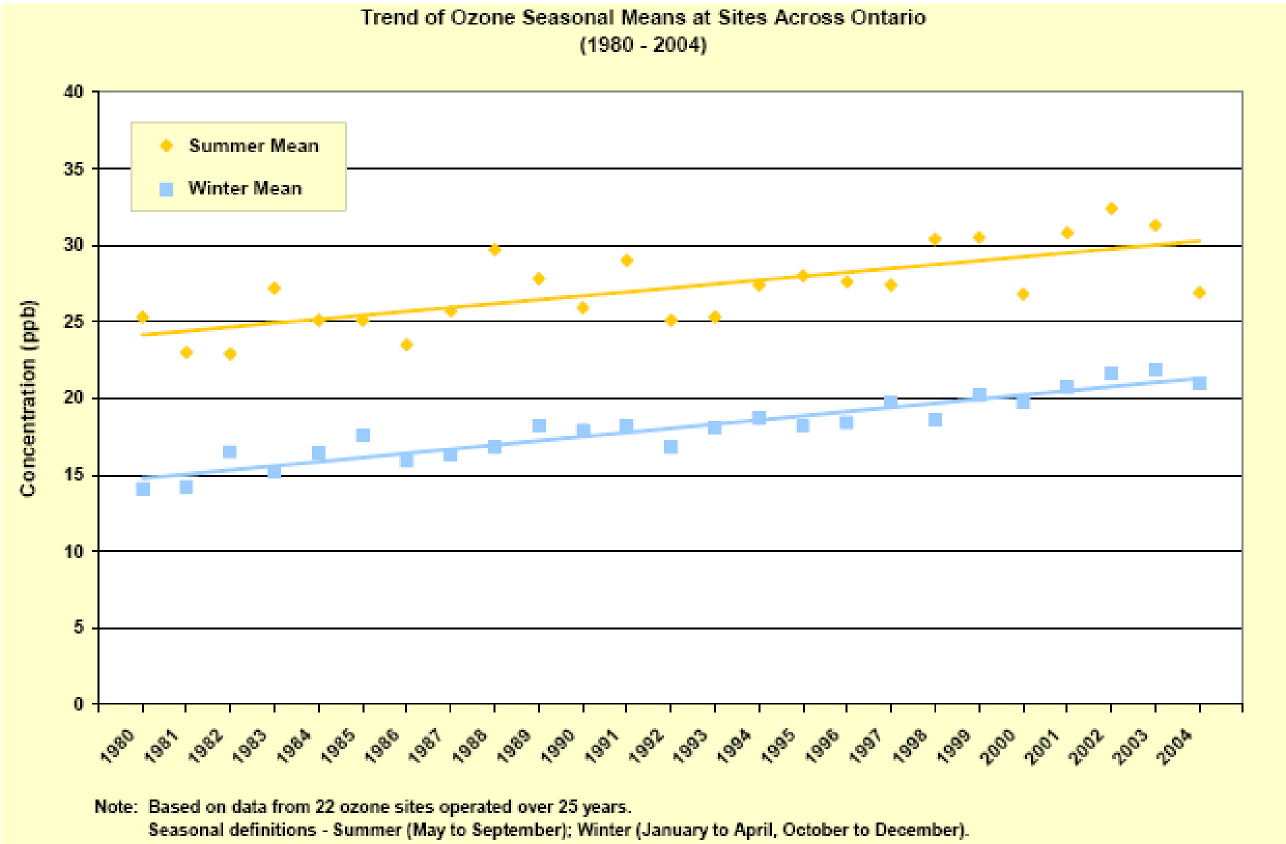

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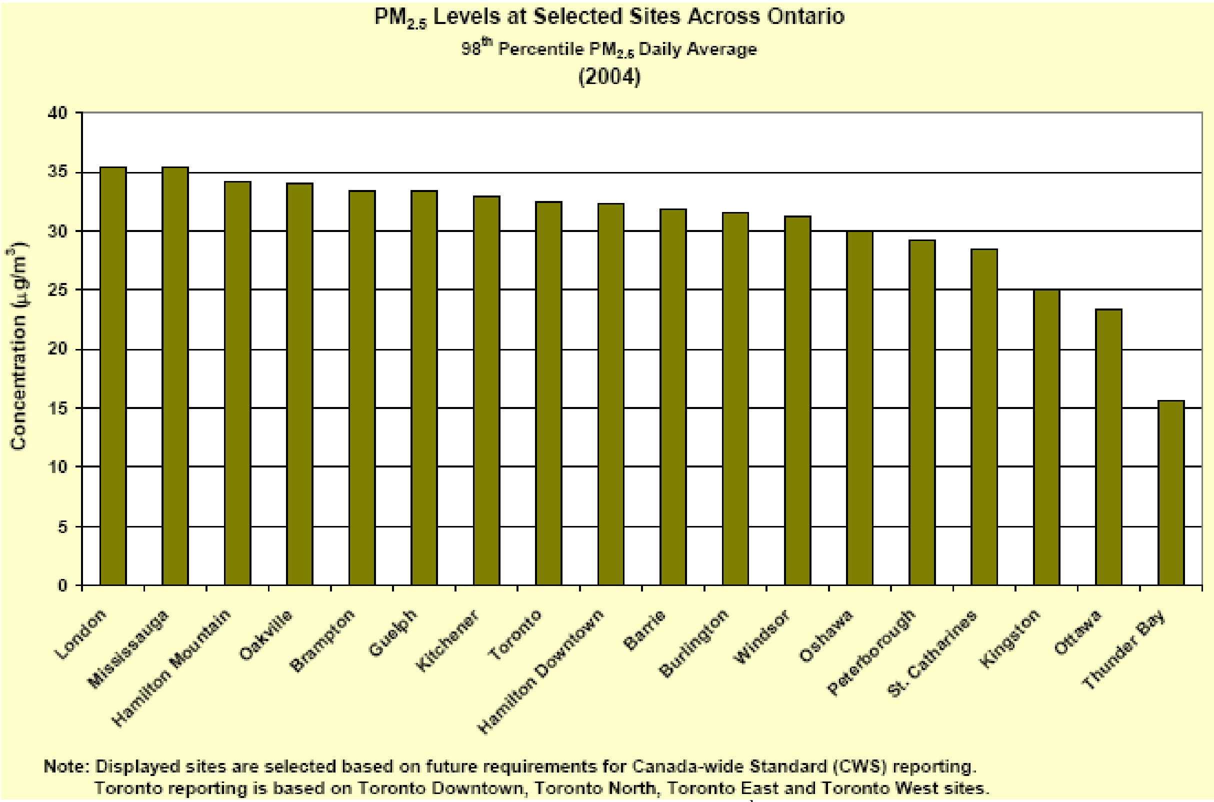

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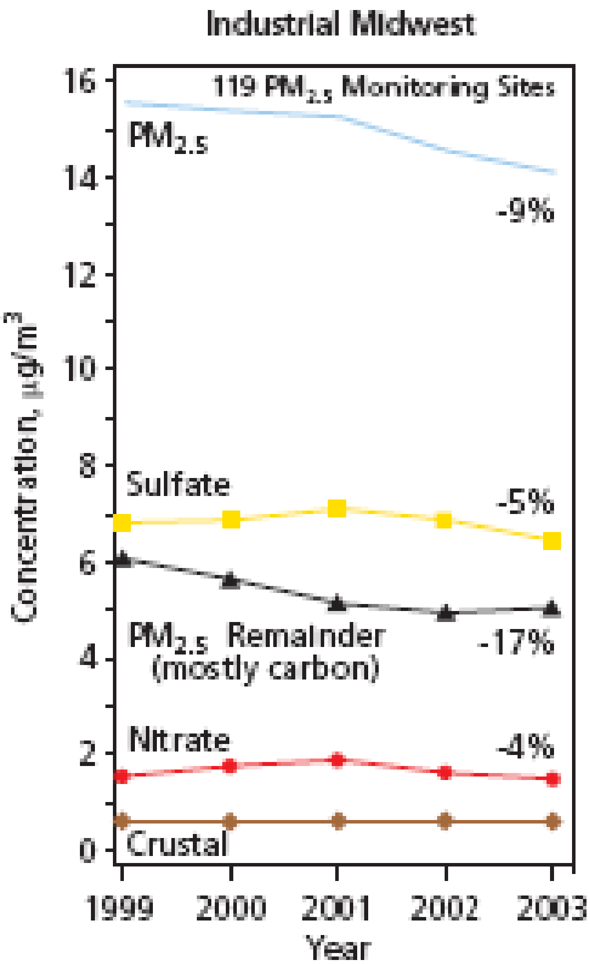

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Coastal Wetland Invertebrate Community Health

Indicator #4501

Note: This indicator has not yet been put into practice. The following evaluation was constructed using input from investigators collecting invertebrate community composition data from Great Lakes coastal wetlands over the last several years. Neither experimental design nor statistical rigor has been used to specifically address the status and trends of invertebrate communities of coastal wetlands of the five Great Lakes.

Assessment: Not Assessed

Purpose

- To directly measure specific components of invertebrate community composition; and
- To infer the chemical, physical and biological integrity and range of degradation of Great Lakes coastal wetlands.

State of the Ecosystem

Development of this indicator is still in progress. Thus, the state of the ecosystem could not be determined using the wetland invertebrate community health indicator during the last 2 years.

Teams of Canadian and American researchers from several research groups (e.g. the Great Lakes Coastal Wetlands Consortium, the Great Lakes Environmental Indicators project investigators, the U.S. Environmental Protection Agency (USEPA) Regional Environmental Monitoring and Assessment Program (REMAP) group of researchers, and others) sampled large numbers of Great Lakes wetlands during the last two years. They have reported an array of invertebrate communities in Great Lakes wetlands in presentations at international meetings, reports, and peer-reviewed journals.

In 2002 the Great Lakes Coastal Wetlands Consortium conducted extensive surveys of wetland invertebrates of the 4 lower Great Lakes. These data are not entirely analyzed to date. However, the Consortium-adopted Index of Biotic Integrity (IBI, Uzarski *et al.* 2004) was applied in wetlands of northern Lake Ontario. The results can be obtained from Environment Canada (Environment Canada and Central Lake Ontario Conservation Authority 2004).

Uzarski *et al.* (2004) collected invertebrate data from 22 wetlands in Lake Michigan and Lake Huron during 1997 through 2001. They determined that wetland invertebrate communities of northern Lakes Michigan and Huron generally produced the highest IBI scores. IBI scores were primarily based on richness and abundance of Odonata, Crustacea plus Mollusca taxa richness, total genera richness, relative abundance Gastropoda, relative abundance Sphaeriidae, Ephemeroptera plus Trichoptera taxa richness, relative abundance Crustacea plus Mollusca, relative abundance Isopoda, Evenness, Shannon Diversity Index, and Simpson Index. Wetlands near Escanaba and Cedarville, Michigan, scored lower than most in the area. A single wetland near the mouth of the Pine River in Mackinac County, MI, consistently scored low, also. In general, all wetlands of Saginaw Bay scored lower than those of northern Lakes Michigan and Huron. However, impacts are more diluted near the outer bay and IBI scores reflect this. Wetlands near Quanicassee and Almeda Beach, MI, consistently scored lower than other Saginaw Bay sites.

Burton and Uzarski (unpublished) also studied drowned river mouth wetlands of eastern Lake Michigan quite extensively since 1998. Invertebrate communities of these systems show linear relationship with latitude. However, this relationship also reflects anthropogenic disturbance. Based on the metrics used (Odonata richness and abundance, Crustacea plus Mollusca richness, rotal genera richness, relative abundance Isopoda, Shannon Index, Simpson Index, Evenness, and relative abundance Ephemeroptera), the sites studied were placed in increasing community health in the order Kalamazoo, Pigeon, Muskegon, White, Pentwater, Pere Marquette, Manistee, Lincoln, and Betsie. The most impacted systems of eastern Lake Michigan are located along southern edge and impacts decrease to the north.

Wilcox *et al.* (2002) attempted to develop wetland IBIs for the upper Great Lakes using microinvertebrates. While they found attributes that showed promise during a single year, they concluded that natural water level changes were likely to alter communities and invalidate metrics. They found that Siskiwit Bay, Bark Bay, and Port Wing had the greatest overall taxa richness with large catches of cladocerans. They ranked microinvertebrate communities of Fish Creek and Hog Island lower than the other four western Lake Superior sites. Their work in eastern Lake Michigan testing potential metrics placed the sites studied in decreasing community health in the order Lincoln River, Betsie River, Arcadia Lake/Little Manistee River, Pentwater River, and Pere Marquette River. This order was primarily based on the median number of taxa, the median Cladocera genera richness, and also a macroinvertebrate metric (number of adult Trichoptera species).

Pressures

Physical alteration and eutrophication of wetland ecosystems continue to be a threat to invertebrates of Great Lakes coastal wetlands. Both can promote establishment of non-native vegetation, and physical alteration can destroy plant communities altogether while changing the natural hydrology to the system. Invertebrate community composition is directly related to vegetation type and densities; changing either of these components will negatively impact the invertebrate communities.

Acknowledgments
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Authors' Commentary
Progress on indicator development has been substantial, and implementation of basin-wide sampling to indicate state of the ecosystem should be possible before SOLEC 2006.

Last Updated
State of the Great Lakes 2005

Coastal Wetland Fish Community Health
Indicator ID: 4502

Overall Assessment: N/A

Note: This indicator has not yet been put into practice. The following evaluation was constructed using input from investigators collecting fish community composition data from Great Lakes coastal wetlands over the last several years. Neither experimental design nor statistical rigor has been used to specifically address the status and trends of fish communities of coastal wetlands of the five Great Lakes.

Purpose

To assess the fish community composition and to infer suitability of habitat and water quality for Great Lakes coastal wetland fish communities.

State of the Ecosystem

Development of this indicator is still in progress. Fish indices of biological integrity have been proposed for selected parts of the ecosystem (e.g., Lake Erie river mouths (Thoma 1999) Michigan and Ontario coastal wetlands (Uzarski *et al*. 2005), and coordinated basinwide sampling has recently been completed by several groups. Thus, progress on indicator development has been substantial, and assessment of data derived from sampling conducted between 2002 and 2005 to indicate the state of the ecosystem should be possible before the next SOLEC. Teams of Canadian and American researchers from several research groups (e.g., the Great Lakes Coastal Wetlands Consortium of the Great Lakes Commission (GLCWC), the U.S. EPA Star Grant funded Great Lakes Environmental Indicators group in Duluth, MN (GLEI), a group of Great Lakes Fishery Commission researchers led by Patricia Chow-Fraser of McMaster University (GLFC), the U.S. EPA REMAP group of researchers led by Tom Simon, and others) have sampled large numbers of Great Lakes wetlands during the last 5 years using comparable methods. They have reported on an array of fish communities in Great Lakes wetlands in presentations at international meetings and in reports. These data are now beginning to appear in refereed journals as individual studies (Uzarski *et al*. 2005, Seilhamer and Chow Fraser 2006) Work is also underway to integrate the datasets for true basinwide assessment (e.g., Brazner *et al*. 2006; Bhagat *et al*. in review). The composition of fish communities is related to plant community type within wetlands and, within plant community type, is related to amount of certain types of anthropogenic disturbance (Uzarski *et al*. 2005; Wei *et al*. 2004, Seilhamer *et al*. 2006; Johnson *et al*. 2006), especially water quality as affected by urban and agricultural development (Seilhamer and Chow Fraser 2006; Bhagat *et al*. in review). Uzarski *et al*. (2005) found no relationship between wetland fish composition and Great Lake suggesting that fish communities of any single Great Lake were more impacted than any other. However, of the 61 wetlands sampled in 2002 from all five lakes, Lakes Erie and Ontario tended to have more wetlands containing cattail communities (a plant community type that correlates with nutrient enrichment), and the fish communities found in cattails tended to have lower richness and diversity than fish communities found in other vegetation types. In contrast, Thoma (1999) and Johnson *et al*. (2006) were unable to find coastal wetlands on the US side of Lake Erie that experienced minimal anthropogenic disturbances. Wetlands found in northern lakes Michigan and Huron tended to have relatively high quality coastal wetland fish communities. The seven wetlands sampled in Lake Superior contained relatively unique vegetation types so fish communities of these wetlands were not directly compared with those of wetlands of other lakes. When the fish communities of reference wetlands are compared across the entire Great Lakes, the most similar sites come from the same ecological province rather than from any single Great Lake or specific wetland types. Data from several GLEI project studies indicate that the characteristic groups of fish species in reference wetlands from each ecological province tend to have similar water temperature and aquatic productivity preferences. When a wetland becomes affected by human development, the fish community changes to the fish community typical of a warmer, richer, more southerly wetland. This finding may help us anticipate the likely effects of regional climate change on the fish communities of Great Lakes coastal wetlands. Brazner *et al*. looked at how 8 different candidate fish IBI components varied by lake, wetland type, ecological province and anthropogenic stress at 80 wetlands across the entire US Great Lakes. Overall, each of these 4 features explained approximately equal amounts of variation in those components.

John Brazner and co-workers from the U.S. EPA Laboratory in Duluth, MN sampled fishes of Green Bay, Lake Michigan, wetlands in 1990, 1991, 1995, 2002, and in 2003. They sampled three lower bay and one middle bay wetland in 2002 and 2003 and their data suggested that these sites were improving in water clarity and plant cover, and supported a greater diversity of both macrophyte and fish species, especially more centrarchid species, than they had in previous years. They also noted that the 2002, and especially 2003, year classes of yellow perch were very large. Brazner's observations suggest that the lower bay wetlands are improving slowly and the middle bay site seems to be remaining relatively stable in moderately good condition (J. Brazner, personal observation). The most turbid wetlands in the lower bay were characterized by mostly warm-water, turbidity-tolerant species such as gizzard shad, *Dorosoma cepedianum*; white bass, *Morone chrysops*; freshwater drum, *Aplodinotus grunniens;* common shiners, *Luxilus cornutus,* and common carp, *Cyprinus carpio*, while the least turbid wetlands in the upper bay were characterized by several centrarchid species, golden shiner, *Notemigonus chrysoleucas*; logperch, *Percina caprodes*; smallmouth bass, *Micropterus dolomieu*, and northern pike, *Esox lucius*. Green sunfish, *Lepomis cyanellus,* was the only important centrarchid in the lower bay in 1991, while in 1995, bluegill and pumpkinseed sunfishes,*L. macrochirus* and *L. gibbosus*, had become much more prevalent and a few largemouth bass, *M. salmoides*, were also present. There were more banded killifish, *Fundulus diaphanus*, in 1995 and 2003 compared with 1991 and white perch were very abundant in 1995, as this exotic species became dominant in the bay. The upper bay wetlands were in relatively good condition based on the fish and macrophyte communities that were observed. Although mean fish species richness was significantly lower in developed wetlands across the whole bay, differences between less developed and more developed wetlands were most pronounced in the upper bay where the highest quality wetlands in Green Bay are found (Brazner 1997).

Round gobies, *Neogobius melanostomus*, were introduced to the St. Clair River in 1990 (Jude *et al*. 1992), and have since spread to all of the Great Lakes. Jude studied them in many tributaries of the Lake Huron-St. Clair River-Lake Erie corridor and found that both species (round and tubenose gobies *Proterorhinus marmoratus*) were very abundant at river mouths and colonized far upstream. They were also found at the mouth of Old Woman Creek in Lake Erie, but not within the wetland proper. Jude and Janssen's work in Green Bay wetlands showed that round gobies had not invaded three of the five sites sampled, but few were found in lower Green Bay along the sandy and rocky shoreline west of Little Tail Point.

Uzarski and Burton (unpublished) consistently collected a few round gobies from a fringing wetland near Escanaba, MI where cobbles were present. In the Muskegon River-Muskegon Lake wetland complex on the eastern shoreline, round gobies are abundant in the heavily rip-rapped harbor entrance to Lake Michigan, Muskegon Lake, and have just begun to enter the river/wetland complex on the east side of Muskegon Lake (D. Jude, personal observations; Ruetz, Uzarski, and Burton, personal observations). Based on intensive fish sampling prior to 2003 at more than 60 sites spanning all of the Great Lakes, round gobies have not been sampled in large numbers at any wetland or been a dominant member of any wetland fish community (Jude *et al*. 2005). Round gobies were collected at 11 of 80 wetlands sampled by the GLEI project (Johnson *et al*. unpublished data). Lapointe (2005) assessed fish-habitat associations in the shallow (<3 m) Canadian waters of the Detroit River in 2004 and 2005 using boat-mounted electorfishing and boat seining techniques. The round goby avoided complex macrophytes in all seasons at upper, mid, and downstream segments of the Detroit River. However, in 2006 beach seining surveys at shoreline sites in Canadian waters of Lake St. Clair, the Detroit River, and western Lake Erie, both tubenose and round gobies were collected in areas with aquatic vegetation (L.D. Corkum, Univ. of Windsor, unpublished data). It seems likely that wetlands may be a refuge for native fishes, at least with respect to the influence of round gobies (Jude *et al*. 2005).

There is little information on the habitat preferences of the tubenose goby within the Great Lakes with the exception of studies on the Detroit River (Lapointe 2005), Lake St. Clair and the St. Clair River (Jude and DeBoe 1996, Pronin *et al*. 1997; Leslie *et al*. 2002). Within the Great Lakes, tubenose goby that were studied at a limited number of sites along the St. Clair River and on the south shore of Lake St. Clair occurred in turbid water associated with rooted submersed vegetation (*Vallisneria americana, Myriophyllum spicatum, Potamogeton richardsonii* and *Chara* sp.) (Leslie *et al*. 2002). Few specimens were found on sandy substrates devoid of vegetation, supporting similar findings by Jude and DeBoe (1996). Leslie *et al*. (2002) collected tubenose goby in water with no or slow flow on clay or alluvium substrates, where turbidity varies and where rooted vegetation was sparse, patchy or abundant. Lapointe (2005) found that the association between tubenose goby and aquatic macrophytes differed seasonally in the Detroit River. For example, tubenose goby was strongly negatively associated with complex macrophytes in the spring and summer, but positively associated with complex macrophytes in the fall (Lapointe 2005). Because tubenose goby shared habitats with fishes representing most ecoethological guilds, Leslie *et al*. (2002) suggested that the tubenose goby would expand its geographic range within the Great Lakes.

Ruffe have never been found in high densities in coastal wetlands anywhere in the Great Lakes. In their investigation of the distribution and potential impact of ruffe on the fish community of a Lake Superior coastal wetland, Brazner *et al*. (1998) concluded that coastal wetlands in western Lake Superior provide a refuge for native fishes from competition with ruffe. The mudflat-preferring ruffe actually avoids wetland habitats due to foraging inefficiency in dense vegetation that characterizes healthy coastal wetland habitats. This suggests that further degradation of coastal wetlands or heavily vegetated littoral habitats could lead to increased dominance of ruffe in shallow water habitats elsewhere in the Great Lakes.

There are a number of carp introductions (see Wetland Restoration and Rehabilitation or common carp discussion) that have the potential for substantial impact on Great Lakes fish communities, including coastal wetlands. Goldfish, *Carassius auratus*, are common in some shallow habitats, and occurred along with common carp young-of-the-year in many of the wetlands we sampled along Green Bay. In addition, there are several other carp species, e.g., grass carp, *Ctenopharyngodon idella,* bighead carp *Hypophthalmichthys nobilis,* and silver carp, *Hypophthalmichthys molitrix* that escaped aquaculture operations and are now in the Illinois River and migrating toward the Great Lakes through the Chicago Sanitary Canal. The black carp, *Mylopharygodon piceus*, has also probably been released, but has not been recorded near the Great Lakes yet. Most of these species attain large sizes; some are planktivorous, and also eat phytoplankton, snails, and mussels, while the grass carp eats vegetation. These species represent yet another substantial threat to food webs in wetlands and nearshore habitats with macrophytes (USFWS 2002).

In 2003, Jude and Janssen (unpublished data) determined that bluntnose minnows, *Pimephales notatus*, and johnny darters, *Etheostoma nigrum,* were almost absent from lower bay wetland sites, but comprised 22% and 6% respectively, of upper bay catches. In addition, other species, usually associated with plants and/or clearer water, such as rock bass, sand shiners *Notropis stramineus,* and golden shiners *Notemigonus crysoleucus,* were also present in upper bay samples, but not in lower bay samples. In 2003, Jude and Janssen found that there were no alewife *Alosa pseudoharengus* or gizzard shad in upper Green Bay site catches when compared with lower bay wetland sites, where they composed 2.7 and 34% respectively of the catches by number.

Jude and Pappas (1992) found that fish assemblage structure in Cootes Paradise, a highly degraded wetland area in Lake Ontario, was very different from other less degraded wetlands analyzed. They used ordination analyses to detect fish-community changes associated with degradation.

Acknowledgments

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Last Updated
SOLEC 2006

Wetland-Dependent Amphibian Diversity and Abundance
Indicator #4504

Overall Assessment

Status: Mixed
Trend: Deteriorating
Primary Factors Determining Status and Trend: Species across the Great Lakes basin exhibited both positive and negative population trend tendencies. Five species exhibited significantly negative species population trends while only one species exhibited a significantly positive species population trend.

Lake-by-Lake Assessment

Lake Superior

Status: Not Assessed
Trend: Undetermined

Lake Michigan

Status: Poor
Trend: Unchanging
Primary Factors Determining Status and Trend: Most species in this lake basin exhibited negative population trend tendencies. However, of the only two significant species population trends, one was positive and one was negative.

Lake Huron

Status: Mixed
Trend: Deteriorating
Primary Factors Determining Status and Trend: Species in this lake basin exhibited both positive and negative population trend tendencies. However, four out of eight species exhibited significantly negative population trends. There were no significantly positive species population trends.

Lake Erie

Status: Mixed
Trend: Deteriorating
Primary Factors Determining Status and Trend: Species in this lake basin exhibited both positive and negative population trend tendencies. Two focal species (Bullfrog and Northern Leopard Frog) exhibited significant population trend declines. Only one species exhibited a significantly positive population trend.

Lake Ontario

Status: Mixed
Trend: Unchanging
Primary Factors Determining Status and Trend: Species in this lake basin exhibited both positive and negative population trend tendencies. Two species exhibited significantly increasing population trends, while only one species showed a significant declining species population trend.

Purpose
To directly measure species composition and relative occurrence of frogs and toads and to indirectly measure the condition of coastal wetland habitat as it relates to factors that influence the health of this ecologically important component of wetland biotic communities.

Ecosystem Objective
To restore and maintain diversity and self-sustaining populations of Great Lakes coastal wetland amphibian communities. Breeding populations of amphibian species across their historical range should be sufficient to maintain populations of each species and overall species diversity (Anonymous 1989).

State of the Ecosystem
Background
Numerous amphibian species occur in the Great Lakes basin and many of these are associated with wetlands during part of their life cycle. Because frogs and toads are relatively sedentary and have semi-permeable skin, they are likely to be more sensitive to, and indicative of, local sources of wetland contamination and degradation than are most other vertebrates. Assessing species composition and relative abundance of calling frogs and toads in Great Lakes wetlands can therefore help to infer wetland habitat quality.

Geographically extensive and long-term monitoring of calling amphibians is possible through the enthusiasm, skill and coordination of volunteer participants trained in the application of standardized monitoring protocols. Information about abundance, distribution and diversity of amphibians provides data for calculating trends in population indices as well as investigating habitat associations, which can contribute to effective long-term conservation strategies.

Status of Amphibians
Since 1995, Marsh Monitoring Program (MMP) volunteers have collected amphibian data at 548 discrete routes across the Great Lakes basin. An annual summary of amphibian routes monitored is provided in Table 1.

Thirteen amphibian species were recorded during the 1995 – 2005 period (Table 2). Spring Peeper was the most frequently detected species and was commonly recorded in full chorus (Call Level Code 3) when it was encountered. Green Frog was detected in more than half of the survey stations and was most often recorded at Call Level Code 1 (calling individuals could be discretely counted). Grey Treefrog, American Toad and Northern Leopard Frog were also common, being recorded in approximately one-third or more of all survey stations. Grey Treefrog was recorded with the second highest average calling code (1.8), indicating that MMP observers usually heard several individuals calling simultaneously at each survey station. Chorus Frog, Bullfrog and Wood Frog were detected in approximately one-quarter of survey stations, while the remaining five species were detected in less than 3 percent of survey stations.

Trends in amphibian occurrence were assessed for eight species commonly detected on MMP routes (Figure 1). For each species, the annual proportion of stations where that species was present within a route was calculated to derive annual indices of occurrence. The overall temporal trend in occurrence for each species was assessed by combining route-level trends in station occurrence. Statistically significant declining trends were detected for American Toad, Bullfrog, Chorus Frog, Green Frog and Northern Leopard Frog. Spring Peeper exhibited a statistically significant increasing population trend.

These data will serve as baseline data with which to compare future survey results. Anecdotal and research evidence suggests that wide variations in occurrence of many amphibian species at a given site is a natural and ongoing phenomenon. Additional years of data will help distinguish whether the patterns observed (i.e., decline in American Toad, Bullfrog, Chorus Frog, Green Frog and Northern Leopard Frog population indices) indicate significant long-term trends or simply natural variation in population sizes inhabiting marsh habitats. Bullfrog, for example, did not experience a significant population index trend from 1995 to 2004 (Crewe *et al.* 2006; Archer *et al.* 2006) but with the addition of 2005 data, its population index declined significantly. Further data are thus required to conclude whether Great Lakes wetlands are successfully sustaining these amphibian populations. MMP amphibian data are being evaluated to determine how information from their community composition can be used to gain a better understanding of Great Lakes coastal wetland condition in response to various human induced stressors.

Future Pressures

Habitat loss and deterioration remain the predominant threat to Great Lakes amphibian populations. Many coastal and inland Great Lakes wetlands are located along watersheds that experience very intensive industrial, agricultural and residential development. Therefore, these wetlands are under continued stress as increased pollution from anthropogenic runoff is washed down watersheds into these sensitive habitats. Combined with other impacts such as water level stabilization, sedimentation, contaminant and nutrient inputs, climate change and invasion of exotic species, Great Lakes wetlands will likely continue to be degraded and as such, should continue to be monitored.

Future Activities

Because of the sensitivity of amphibians to their surrounding environment and the growing international concern about amphibian population status, amphibians in the Great Lakes basin and elsewhere will continue to be monitored. Wherever possible, efforts should be made to maintain high quality wetland habitat as well as associated upland areas adjacent to coastal wetlands. There is also a need to address other impacts that are detrimental to wetland health such as inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made in this area, more work remains for many wetland areas that have yet to receive restoration efforts.

Further Work Necessary

Effective monitoring of Great Lakes amphibians requires accumulation of many years of data, using a standardized protocol, over a large geographic expanse. A reporting frequency for SOLEC of five years would be appropriate because amphibian populations naturally fluctuate through time, and a five-year timeframe would be sufficient to indicate noteworthy changes in population indices. More rigorous studies will relate trends in species occurrence or relative abundance to environmental factors. Reporting will be improved with establishment of a network of survey routes that accurately represent the full spectrum of marsh habitat in the Great Lakes basin.

Most MMP amphibian survey routes have been georeferenced to the survey station level. Volunteer recruitment has also improved significantly since the last status reporting period. Four additional important tasks are in progress: 1) develop the SOLEC wetland amphibian indicator as an index for evaluating coastal wetland health; 2) improve the program's capacity to monitor and report on status of wetland specific Beneficial Use Impairments among Great Lakes Areas of Concern; 3) develop and improve the program's capacity to train volunteer participants to identify and survey amphibians following standard MMP protocols, and; 4) develop the capacity to incorporate a regional MMP coordinator network component into the MMP to improve regional and local delivery of the program throughout the Great Lakes basin. Also, further work is required to determine the relationship between calling codes used to record amphibian occurrence and survey count estimates.

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SOLEC 2006

Year	Number of Routes
1995	115
1996	177
1997	208
1998	168
1999	163
2000	158
2001	166
2002	156
2003	156
2004	146
2005	177

Table 1. Number of routes surveyed for amphibians within the Great Lakes basin, from 1995 to 2005.
Source: Marsh Monitoring Program

Species	Percent Station-Years Present [1]	Average Calling Code
Spring Peeper	69.3	2.5
Green Frog	54.3	1.3
Grey Treefrog	39.2	1.8
American Toad	36.9	1.5
Northern Leopard Frog	31.1	1.3
Chorus Frog	26.5	1.7
Bullfrog	25.8	1.3
Wood Frog	18.0	1.6
Fowler's Toad	2.4	1.4
Pickerel Frog	2.4	1.1
Cope's Grey Treefrog	1.6	1.4
Mink Frog	1.2	1.2
Blanchard's Cricket Frog	0.6	1.5

[1] MMP survey stations monitored for multiple years considered as individual samples

Table 2. Frequency of occurrence (Percent Station-Years Present) and average Call Level Code for amphibian species detected at MMP survey stations within the Great Lakes basin, from 1995 through 2005. Average calling codes are based on the three level call code standard for all MMP amphibian surveys; Code 1 = little overlap among calls, numbers of individuals can be determined, Code 2 = some overlap, numbers can be estimated, Code 3 = much overlap of calls, too numerous to be estimated.
Source: Marsh Monitoring Program

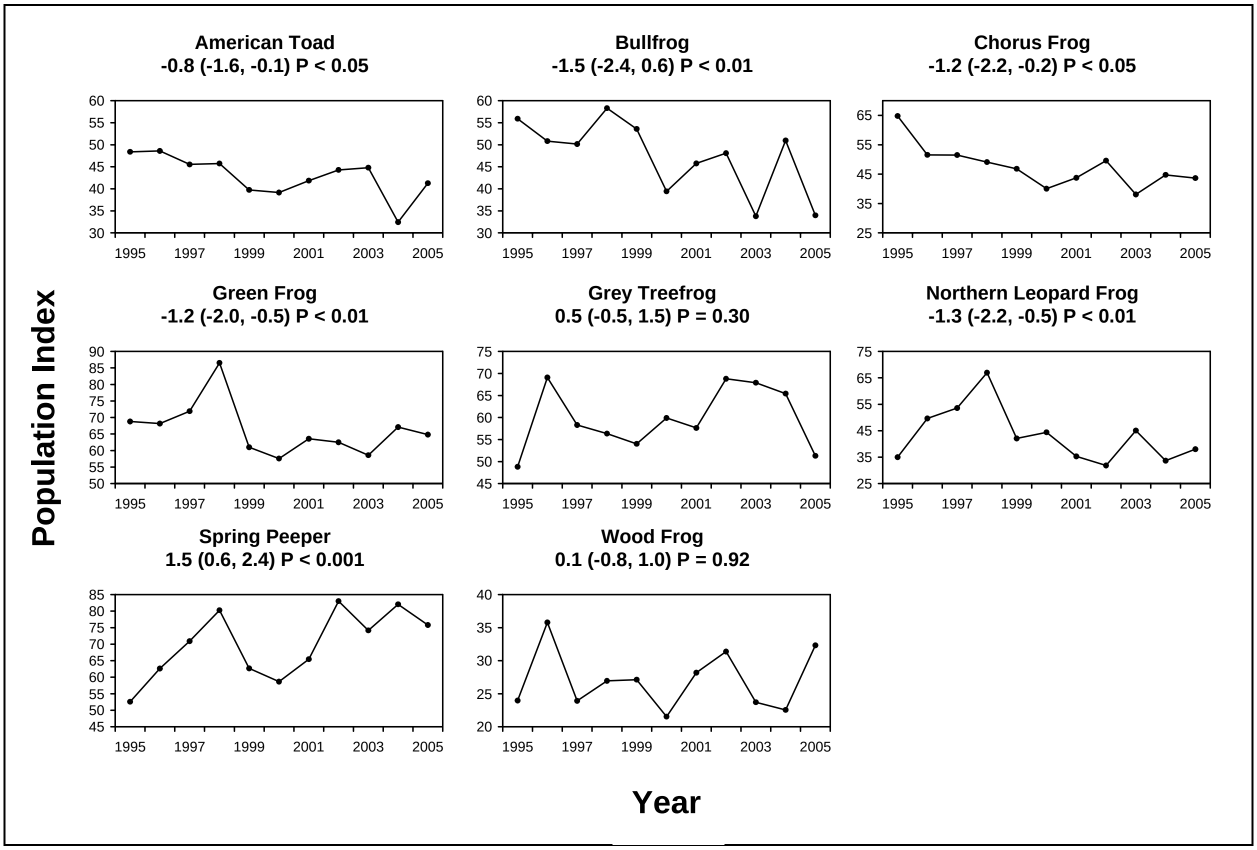

Figure 1. Trends (percent annual change) in station occurrence (population index) of eight amphibian species commonly detected at Marsh Monitoring Program routes, from 1995 to 2005. Values in parentheses are upper and lower 95% confidence limits, respectively, for trend values given.
Source: Marsh Monitoring Program

Contaminants in Snapping Turtle Eggs

Indicator #4506

Overall Assessment

Status:	Mixed
Trend:	Trend not assessed
Primary Factors Determining Status and Trend	Contaminants at AOCs exceeded concentrations at reference sites. Dioxin equivalents and DDE concentrations in eggs exceeded the Canadian Environmental Quality Guidelines, and sum PCBs exceeded partial restriction guidelines for consumption from some sites.

Lake-by-Lake Assessment

Lake Superior

Status:	Not Assessed
Trend:	Trend Not Assessed due to insufficient data

Lake Michigan

Status:	Not Assessed
Trend:	Trend Not Assessed due to insufficient data

Lake Huron

Status:	Not Assessed
Trend:	Trend Not Assessed due to insufficient data

Lake Erie

Status:	Mixed
Trend:	Trend Not Assessed
Primary Factors Determining Status and Trend	Contaminants at AOCs exceeded concentrations at reference sites. Dioxin equivalents and DDE concentrations in eggs exceeded the Canadian Environmental Quality Guidelines, and sum PCBs exceeded partial restriction guidelines for consumption from some sites.

Lake Ontario

Status:	Mixed
Trend:	Trend Not Assessed
Primary Factors Determining Status and Trend	Contaminants at AOCs exceeded concentrations at reference sites. Dioxin equivalents and DDE concentrations in eggs exceeded the Canadian Environmental Quality Guidelines, and sum PCBs exceeded partial restriction guidelines for consumption from some sites.

Purpose

•To assess the accumulation of organochlorine chemicals and mercury in snapping turtle eggs;
•To assess contaminant trends and physiological and ecological endpoints in snapping turtles; and
•To obtain a better understanding of the impact of contaminants on the physiological and ecological health of the individual turtles and wetland communities.

Ecosystem Objective
Snapping turtle populations in Great Lakes coastal wetlands and at contaminated sites should not exhibit significant differences in concentrations of organochlorine chemicals, mercury, and other chemicals, compared to turtles at clean (inland) reference site(s). This indicator supports Annexes 1, 2, 11 and 12 of the Great Lakes Water Quality Agreement.

State of the Ecosystem
Background
Snapping turtles inhabit (coastal) wetlands in the Great Lakes basin, particularly the lower Great Lakes. While other Great Lakes wildlife species may be more sensitive to contaminants than snapping turtles, there are few other species that are as long-lived, as common year-round, inhabit such a wide variety of habitats, and yet are limited in their movement among wetlands. Snapping turtles are also at the top in the aquatic food web and bioaccumulate contaminants. Plasma and egg tissues offer a nondestructive method to monitor recent exposure to chemicals as well as an opportunity for long-term contaminant and health monitoring. Since they inhabit coastal wetlands throughout the lower Great Lakes basin, they allow for multi-site comparisons on a temporal and spatial basis. Consequently, snapping turtles are a very useful biological indicator species of local wetland contaminant trends and the effects of these contaminants on wetland communities throughout the lower Great Lakes basin.

Status of Contaminants in Snapping Turtle Eggs
For more than 20 years, the Canadian Wildlife Service (CWS) has periodically collected snapping turtle eggs and examined the species' reproductive success in relation to contaminant levels on a research basis. More recently (2001-2005), CWS is examining the health of snapping turtles relative to contaminant exposure in Canadian Areas of Concern (AOCs) of the lower Great Lakes basin. The work by the CWS has shown that contaminants in snapping turtle eggs differ over time and among sites in the Great Lakes basin, with significant differences observed between contaminated and reference sites (Bishop et al. 1996, 1998). Snapping turtle eggs collected at two Lake Ontario sites (Cootes Paradise and Lynde Creek) had the greatest concentrations of polychlorinated dioxins and number of furans (Bishop et al. 1996, 1998). Eggs from Cranberry Marsh (Lake Ontario) and two Lake Erie sites (Long Point and Rondeau Provincial Park) had similar levels of polychlorinated biphenyls (PCBs) and organochlorines among the study sites (Bishop et al. 1996, 1998). Eggs from Akwesasne (St. Lawrence River) contained the greatest level of PCBs (Bishop et al. 1998). From 1984 to 1990/91, levels of PCBs and dichlorodiphenyl-dichloroethene (DDE) increased significantly in eggs from Cootes Paradise and Lynde Creek, and levels of dioxins and furans decreased significantly at Cootes Paradise (Struger et al. 1993; Bishop et al. 1996). More recently, American researchers have also used snapping turtles as indicators of contaminant exposure (Dabrowska et al. 2006).

Eggs with the greatest contaminant levels also showed the poorest developmental success (Bishop et al. 1991, 1998). Rates of abnormal development of snapping turtle eggs from 1986-1991 were highest at all four Lake Ontario sites compared to other sites studied (Bishop et al. 1998).

Lake Erie and connecting channels

From 2001 to 2003, CWS collected snapping turtle eggs at or near three Canadian Lake Erie or connecting channels AOCs: Detroit River, St. Clair River, and Wheatley Harbour AOCs, as well as two reference sites. Mean sum PCBs ranged from 0.02 µg/g at Algonquin Park (reference site) to 0.93 µg/g at Detroit River. Sum PCB levels were highest at Turkey Creek (Detroit River), followed by Wheatley Harbour, then St. Clair NWA (near St. Clair River AOC) and lastly, Algonquin Provincial Park, an inland reference site (Figure 1). Dioxin equivalents of sum PCBs in eggs from the Detroit River, Wheatley Harbour, and St. Clair River AOCs, and p,p'-DDE levels in eggs from the Wheatley Harbour and the Detroit River AOCs, exceeded the Canadian Environmental Quality Guidelines. Sum PCBs in eggs from the Detroit River and Wheatley Harbour AOCs exceeded partial restriction guidelines for consumption (de Solla and Fernie 2004). An American study in 1997 funded by the Great Lakes Protection Fund found that sum PCBs appeared to be higher in the American AOCs in Ohio, where concentrations ranged from 0.18 to 3.68 µg/g; concentrations were highest from the Ottawa River AOC, followed by the Maumee River AOC, Ashtabula River AOC, and the Black River within Maumee River AOC (Dabrowska et al. 2006). The reference sites used near the American AOCs may have higher contaminant exposure than the Canadian reference sites.

Lake Ontario and connecting channels

From 2002 to 2003, CWS collected snapping turtle eggs at or near seven Lake Ontario and connecting channel AOCs: Hamilton Harbour, Niagara River (Ontario), St. Lawrence River (Ontario), and Toronto, as well as two reference sites. Mean sum PCBs varied ranged from 0.02 µg/g at Algonquin Park (reference site) to 1.76 µg/g at Hamilton Harbour (Grindstone Creek). Sum PCB levels were highest at Hamilton Harbour (Grindstone Creek), followed by the second site at Hamilton Harbour (Cootes Paradise), then Lyons Creek (Niagara River) (Figure 1). There is evidence that PCB levels in snapping turtle eggs have been declining at the inland reference site of Algonquin Park (1981-2003) and the heavily contaminated Hamilton Harbour AOC (1984-2003). Long term trends at the St. Lawrence River AOC are difficult to determine, due to the high degree of variability of contaminant sources in the area; PCBs have been reported as high as 738 µg/g at Turtle Creek, Akwesasne (de Solla et al. 2001).

Flame retardants (polybrominated diphenyl ethers [PBDEs]) are one of the chemicals of emerging concern because they are bioaccumulative and may potentially affect wildlife and human health. Sum PBDE concentrations varied, but they were an order of magnitude lower than sum PCBs in snapping turtle eggs collected from the seven AOCs (2001-2003). Sum PBDE levels were lowest at Algonquin Park (6.1 ng/g sum PDBE), where airborne deposition is likely the main contaminant source, and greatest at the Hamilton Harbour (Cootes Paradise; 67.6 ng/g) and Toronto (Humber River; 107.0 ng/g) AOCs, indicative of urban areas likely being the main source of PBDEs.

Pressures

Future pressures for this indictor include all sources of toxic contaminants that currently have elevated concentrations (e.g. PCBs, dioxins), as well as contaminants whose concentrations are expected to increase in Great Lakes wetlands (e.g. PBDEs). Non-bioaccumulative compounds in which there are chronic exposures (e.g. PAHs) also pose a potential threat. Snapping turtle populations face additional pressures from harvesting of adult turtles, road-side killings during the nesting season in June, and habitat destruction.

Management Implications

The contaminants measured by are persistent and bioaccumulative, with diet being the primary source of exposure for snapping turtles, and thus indicate contamination that is available throughout the aquatic food web. Although commercial collection of snapping turtles has ceased, collection for private consumption persists. Therefore, consumption restrictions are required at selected AOCs. Currently, only eggs are routinely sampled for contaminants, but body burdens of females could be estimated using egg burdens, and thus used for determining if consumption guidelines are needed. At some AOCs (i.e., Niagara River [Lyons Creek], Hamilton Harbour), there are localized sediment sources of contaminants that may be rehabilitated through dredging or capping. Mitigation of contaminant sources should eventually reduce contaminant burdens in snapping turtles.

Comments from the author(s)

Contaminant status of snapping turtles should be monitored on a regular basis across the Great Lakes basin where appropriate. Once the usefulness of the indicator is confirmed, a complementary U.S. program is required to interpret basin-wide trends. This species offers an excellent opportunity to monitor contaminant concentrations in coastal wetland populations. Newly emerging contaminants also need to be examined in a long-term monitoring program. As with all long-term monitoring programs, and for any indicator species used to monitor persistent bioaccumulative contaminants, standardization of contaminant data is necessary for examining temporal and spatial trends or combining data from different sources.

Acknowledgments

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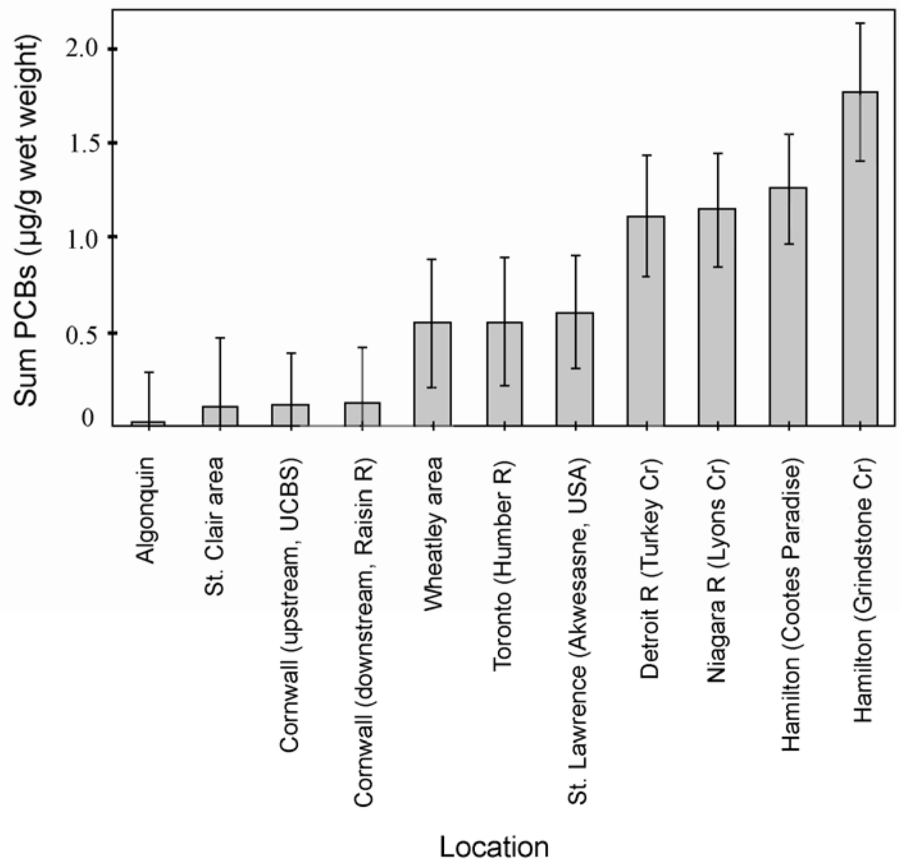

Figure 1. Sum PCB concentrations in snapping turtle eggs from various Canadian locations throughout the lower Great Lakes basin, 2001 through 2003. Means ± standard errors are presented.
Source: Canadian Wildlife Service

Wetland-Dependent Bird Diversity and Abundance
Indicator #4507

Overall Assessment

Status:	Mixed
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Species across the Great Lakes basin exhibited both positive and negative population trend tendencies. Significantly negative population trends occurred for 14 species, while only six species exhibited significantly positive population trends.

Lake-by-Lake Assessment
Lake Superior

Status:	Not Assessed
Trend:	Undetermined

Lake Michigan

Status:	Mixed
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Species in this lake basin exhibited both positive and negative population trend tendencies. Despite an equal number of significantly positive and negative trends among species, certain focal species did not occur at a level sufficient for trend analysis, or were absent from monitoring stations.

Lake Huron

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Most species in this lake basin exhibited a negative population trend. Eight significantly negative species population trends occurred, while there were no significantly positive species population trends.

Lake Erie

Status:	Mixed
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Species in this lake basin exhibited both positive and negative population trend tendencies. Significantly negative population trends occurred for seven species, while only three species exhibited significantly positive population trends.

Lake Ontario

Status:	Mixed
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Species in this lake basin exhibited both positive and negative population trend tendencies. Significantly negative population trends occurred for six species, while only two species exhibited significantly positive population trends.

Purpose

- To assess wetland bird species composition and relative abundance, and to infer condition of coastal wetland habitat as it relates to factors that influence the biological condition of this ecologically and culturally important component of wetland communities.

State of the Ecosystem

Background

Assessments of wetland-dependent bird diversity and abundance in the Great Lakes are used to evaluate health and function of coastal and inland wetlands. Breeding birds are valuable components of Great Lakes wetlands and rely on the physical, chemical and biological condition of their habitats, particularly during breeding. Presence and abundance of breeding individuals therefore provide a valuable source of information about wetland status and population trends. Because several wetland-dependent birds are listed as species at risk due to the loss and degradation of their habitats, the combination of long-term monitoring data and analysis of habitat characteristics can help to assess how well Great Lakes coastal wetlands are able to provide habitat for these sensitive species as well as other birds and wetland-dependent wildlife.

Geographically extensive and long-term monitoring of wetland-dependent birds is possible through the enthusiasm, skill and coordination of volunteer participants trained in the application of standardized monitoring protocols. Information about abundance, distribution and diversity of marsh birds provides data for calculating trends in population indices as well as investigating habitat associations which can contribute to effective, long-term conservation strategies.

Status of Wetland-Dependent Birds

Since 1995, Marsh Monitoring Program (MMP) volunteers have collected bird data at 508 discrete routes across the Great Lakes basin. An annual summary of bird routes monitored is provided in Table 1.

From 1995 through 2005, MMP volunteers recorded 56 bird species that use marshes (wetlands dominated by non-woody emergent plants) for feeding, nesting or both throughout the Great Lakes basin. Red-winged Blackbird was the most commonly recorded non-aerial foraging bird species observed by MMP participants, followed by Swamp Sparrow, Marsh Wren and Yellow Warbler. Among birds that nest exclusively in marsh habitats, the most commonly recorded species was Marsh Wren, followed by Virginia Rail, Common Moorhen, Pied-billed Grebe, American Coot and Sora. Among bird species that typically forage in the air above marshes, Tree Swallow and Barn Swallow were the two most commonly recorded bird species.

With eleven years of data collected across the Great Lakes basin, the MMP is becoming an established and recognized long-term marsh bird population monitoring program. Bird species occurrence, abundance, activity and detectability vary naturally among years and within seasons. Population indices and trends (i.e., average annual percent change in population index) are presented for several bird species recorded at Great Lakes MMP routes, from 1995 through 2005 (Figure 1). Species with significant basin-wide declines were American Coot (not shown), Black Tern, Blue-winged Teal (not shown), Common Grackle (not shown), Common Moorhen (not shown), Least Bittern, undifferentiated Common Moorhen/American Coot (calls of these two species are difficult to distinguish from one another), Northern Harrier (not shown), Pied-billed Grebe, Red-winged Blackbird, Sora, Tree Swallow and Virginia Rail (Figure 1). Statistically significant basin-wide population increases were observed for Common Yellowthroat, Mallard, Northern Rough-winged Swallow (not shown), Purple Martin (not shown), Trumpeter Swan (not shown), Willow Flycatcher (not shown) and Yellow Warbler (not shown). American Bittern and Marsh Wren populations did not show a significant trend in abundance indices from 1995 through 2005 (Figure 1). Declines in population indices of species that use wetlands almost exclusively for breeding such as Least Bittern, Black Tern, Common Moorhen, American Coot, Sora, Pied-billed Grebe and Virginia Rail, combined with an increase in some wetland edge and generalist species (e.g., Common Yellowthroat, Willow Flycatcher and Mallard) suggest changes in wetland habitat conditions may be occurring. Difference in habitats, regional population densities, timing of survey visits, annual weather variability and other factors likely interplay with water levels to explain variation in wetland dependent bird populations. American Bittern, for example, showed a significant declining population index from 1995 to 2004 (Crewe *et al.* 2006; Archer *et al.* 2006) but recently its population index has rebounded. As such, further years of data will hopefully help explain natural population variation from significant population trends.

Future Pressure
Future pressures on wetland-dependent birds will likely include continuing loss and degradation of important breeding habitats through wetland loss, water level stabilization, sedimentation, contaminant and nutrient inputs and invasion of exotic plants and animals.

Future Activities
Wherever possible, efforts should be made to maintain high quality wetland habitat and adjacent upland areas. There is also a need to address other impacts that are detrimental to wetland health such as water level stabilization, invasive species and inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made, considerably more conservation and restoration work is needed to ensure maintenance of healthy and functional wetland habitats throughout the Great Lakes basin.

Further Work Necessary
MMP wetland monitoring activities will continue across the Great Lakes basin. Continued monitoring of at least 100 routes through 2006 is projected to provide good resolution for most of the wetland-dependent birds recorded by MMP volunteers. Recruitment and retention of program participants will therefore continue to be a high priority. Priority should also be placed on establishing regional goals and acceptable thresholds for species-specific abundance indices and species community compositions. Assessments to determine relationships among survey indices, bird population parameters and critical environmental parameters are also needed.

Previous studies have ascertained marsh bird habitat associations using MMP bird and habitat data. As more data is accumulated, these studies should be periodically updated in order to provide a better understanding of the relationships between wetland bird species and habitat. Most MMP bird survey routes have been georeferenced to the level of individual survey stations. Volunteer recruitment has also improved significantly since the last status reporting period. Five additional important tasks are in progress: 1) develop the SOLEC wetland bird indicator as an index for evaluating coastal wetland health; 2) improve the program's capacity to monitor and report on status of wetland specific Beneficial Use Impairments among Great Lakes Areas of Concern; 3) improve and revise MMP bird survey protocols to coincide with continentally accepted marsh bird monitoring survey standards; 4) develop and improve the program's capacity to train volunteer participants to identify and survey marsh birds following standard MMP protocols, and; 5) develop the capacity to incorporate a regional MMP coordinator network component into the MMP to improve regional and local delivery of the program throughout the Great Lakes basin.

Although more frequent updates are possible, reporting trends in marsh bird population indices every five or six years is most appropriate for this indicator. A variety of efforts are underway to enhance reporting breadth and efficiency.

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Authors: Steve Timmermans and Ryan Archer, Bird Studies Canada
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Year	Number of Routes
1995	145
1996	177
1997	175
1998	151
1999	154
2000	153
2001	146
2002	170
2003	131
2004	118
2005	183

Table 1. Number of routes surveyed for marsh birds within the Great Lakes basin, from 1995 to 2005.

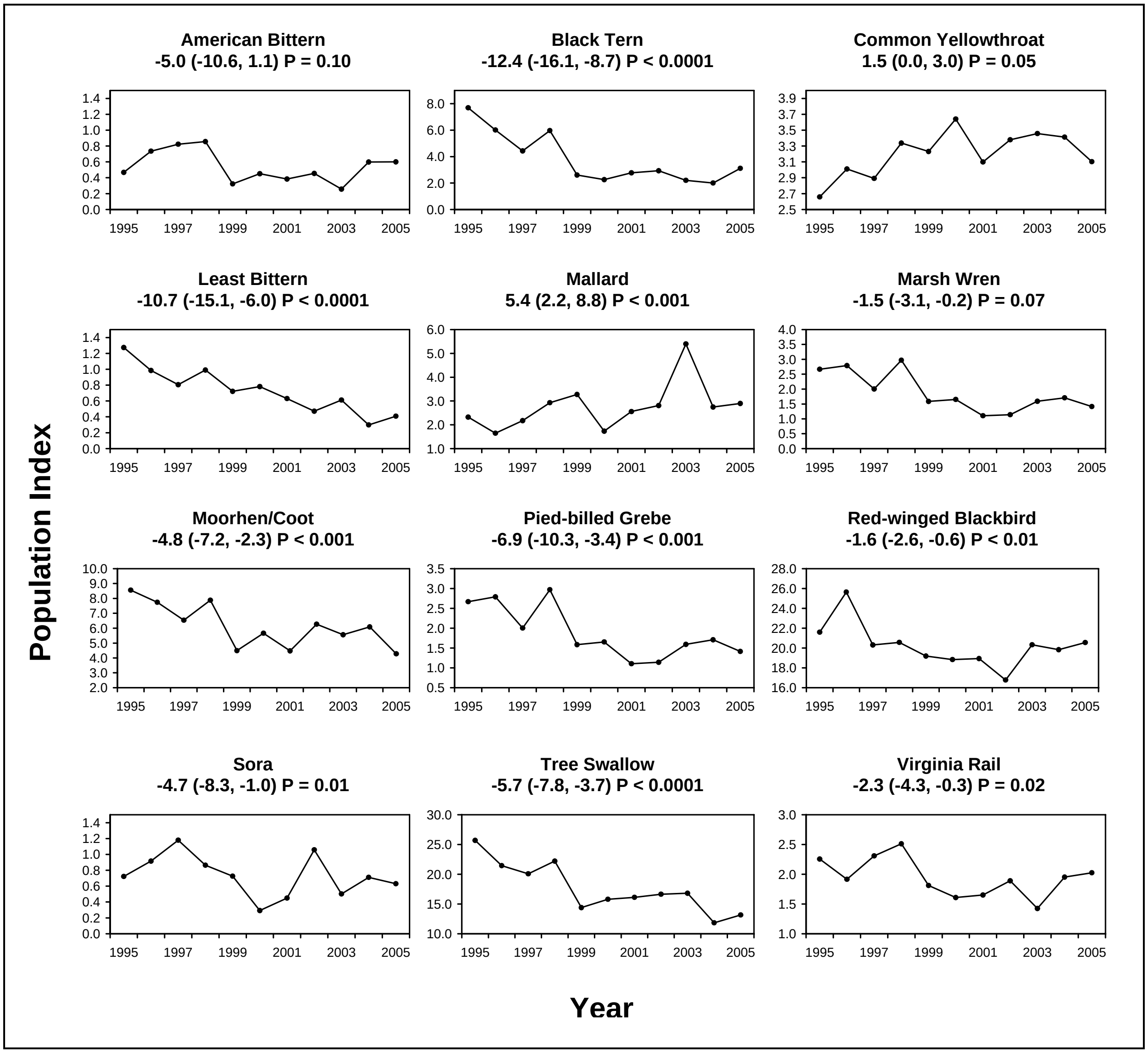

Figure 1. Trends (percent annual change) in relative abundance (population index) of marsh nesting and aerial foraging bird species detected at Marsh Monitoring Program routes, from 1995 to 2005. Values in parentheses are upper and lower 95% confidence limits, respectively, for trend values given.
Source: Marsh Monitoring Program

Coastal Wetland Area by Type
Indicator #4510

Overall Assessment
Status: **Mixed**
Trend: **Deteriorating**

Lake-by-Lake Assessment
Lake Superior
Status: Not Assessed
Trend: Undetermined

Lake Michigan
Status: Not Assessed
Trend: Undetermined

Lake Huron
Status: Not Assessed
Trend: Undetermined

Lake Erie
Status: Not Assessed
Trend: Undetermined

Lake Ontario
Status: Not Assessed
Trend: Undetermined

Purpose
To assess the periodic changes in area (particularly losses) of coastal wetland types, taking into account natural lake level variations.

Ecosystem Objective
Maintain total areal extent of Great Lakes coastal wetlands, ensuring adequate representation of coastal wetland types across their historical range (Great Lakes Water Quality Agreement, Annexes 2 and 13).

State of the Ecosystem
The status of this indicator has not been updated since the *2005 State of the Lakes* report. Future updates to the status of this indicator will require the repeated collection and analysis of remotely sensed information. Currently, technologies and methods are being assessed for an ability to estimate wetland extent. Next steps, including determination of funding and resource needs, as well as pilot investigations must occur before an indicator status update can be made. The timeline for this is not yet determined. However, once a methodology is established, it will be applicable for long-term monitoring of this indicator, which is imperative for an improved understanding of wetland functional responses and adaptive management. The 2005 assessment of this indicator follows.

Wetlands continue to be lost and degraded, yet the ability to track and determine the extent and rate of this loss in a standardized way is not yet feasible.

In an effort to estimate the extent of coastal wetlands in the basin, the Great Lakes Coastal Wetland Consortium (GLCWC) coordinated completion of a binational coastal wetland database. The project involved building from existing Canadian and U.S. coastal wetland databases (Environment Canada and Ontario Ministry of Natural Resources 2003, Herdendorf *et al*. 1981a-f), and incorporating additional auxiliary Federal, Provincial and State data to create a more complete, digital Geographic Information System (GIS) vector database. All coastal wetlands in the database were classified using a Great Lakes hydrogeomorphic coastal wetland classification system (Albert *et al*. 2005). The project was completed in 2004.The GIS database provides the first spatially explicit seamless binational summary of coastal wetland distribution in the Great Lakes system. Coastal wetlands totaling 216,743 ha have been identified within the Great Lakes and connecting rivers up to Cornwall, Ontario (Figure 1). However, due to existing data limitations, estimates of coastal wetland extent, particularly for the upper Great Lakes are acknowledged to be incomplete.

Despite significant loss of coastal wetland habitat in some regions of the Great Lakes, the lakes and connecting rivers still support a diversity of wetland types. Barrier protected coastal wetlands are a prominent feature in the upper Great Lakes, accounting for over 60,000 ha of the identified coastal wetland area in Lake Superior, Lake Huron and Lake Michigan (Figure 2). Lake Erie supports 22,057 ha of coastal wetland, with protected embayment wetlands accounting for over one third of the total area (Figure 2). In Lake Ontario, barrier protected and drowned rivermouth coastal wetlands account for 19,172 ha, approximately three quarters of the total coastal wetland area.

Connecting rivers within the Great Lakes system also support a diverse and significant quantity of wetlands (Figure 3). The St. Clair River delta occurs where the St. Clair River outlets into Lake St. Clair, and it is the most prominent single wetland feature accounting for over 13,000 ha. The Upper St. Lawrence River also supports a large area of wetland habitats that are typically numerous small embayment and drowned rivermouth wetlands associated with the Thousand Island region and St. Lawrence River shoreline.

Pressures

There are many stressors which have and continue to contribute to the loss and degradation of coastal wetland area. These include: filling, dredging and draining for conversion to other uses such as urban, agricultural, marina, and cottage development; shoreline modification; water level regulation; sediment and nutrient loading from watersheds; adjacent land use; invasive species, particularly non-native species; and climate variability and change. The natural dynamics of wetlands must be considered in addressing coastal wetland stressors. Global climate variability and change have the potential to amplify the dynamics by reducing water levels in the system in addition to changing seasonal storm intensity and frequency, water level fluctuations and temperature.

Management Implications

Many of the pressures result from direct human actions, and thus, with proper consideration of the impacts, can be reduced. Several organizations have designed and implemented programs to help reduce the trend toward wetland loss and degradation.

Because of growing concerns around water quality and supply, which are key Great Lakes conservation issues, and the role of wetlands in flood attenuation, nutrient cycling and sediment trapping, wetland changes will continue to be monitored closely. Providing accurate useable information to decision-makers from government to private landowners is critical to successful stewardship of the wetland resource.

Comments from the author(s)

Development of improved, accessible, and affordable remote sensing technologies and information, along with concurrent monitoring of other Great Lakes indicators will aid in implementation and continued monitoring and reporting of this indicator.

The GLCWC database represents an important step in establishing a baseline for monitoring and reporting on Great Lakes coastal wetlands including extent and other indicators. Affordable and accurate remote sensing methodologies are required to complete the baseline and begin monitoring change in wetland area by type in the future. Other GLCWC-guided research efforts are underway to assess the use of various remote sensing technologies in addressing this current limitation. Preliminary results from these efforts indicate the potential of using radar imagery and methods of hybrid change detection for monitoring changes in wetland type and conversion.

The difficult decisions on how to address human-induced stressors causing wetlands loss have been considered for some time. Several organizations and programs continue to work to reverse the trend, though much work remains. A better understanding of wetland functions, through additional research and implementation of biological monitoring within coastal wetlands, will help ensure that wetland quality is maintained in addition to areal extent. An educated public is critical to ensuring that wise decisions about the stewardship of the Great Lakes basin ecosystem are made.

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Figure 1. Great Lakes coastal wetland distribution and total area by lake and river.
Source: Great Lakes Coastal Wetlands Consortium

Figure 2. Coastal wetland area by geomorphic type within lakes of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

Figure 3. Coastal wetland area by geomorphic type within connecting rivers of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

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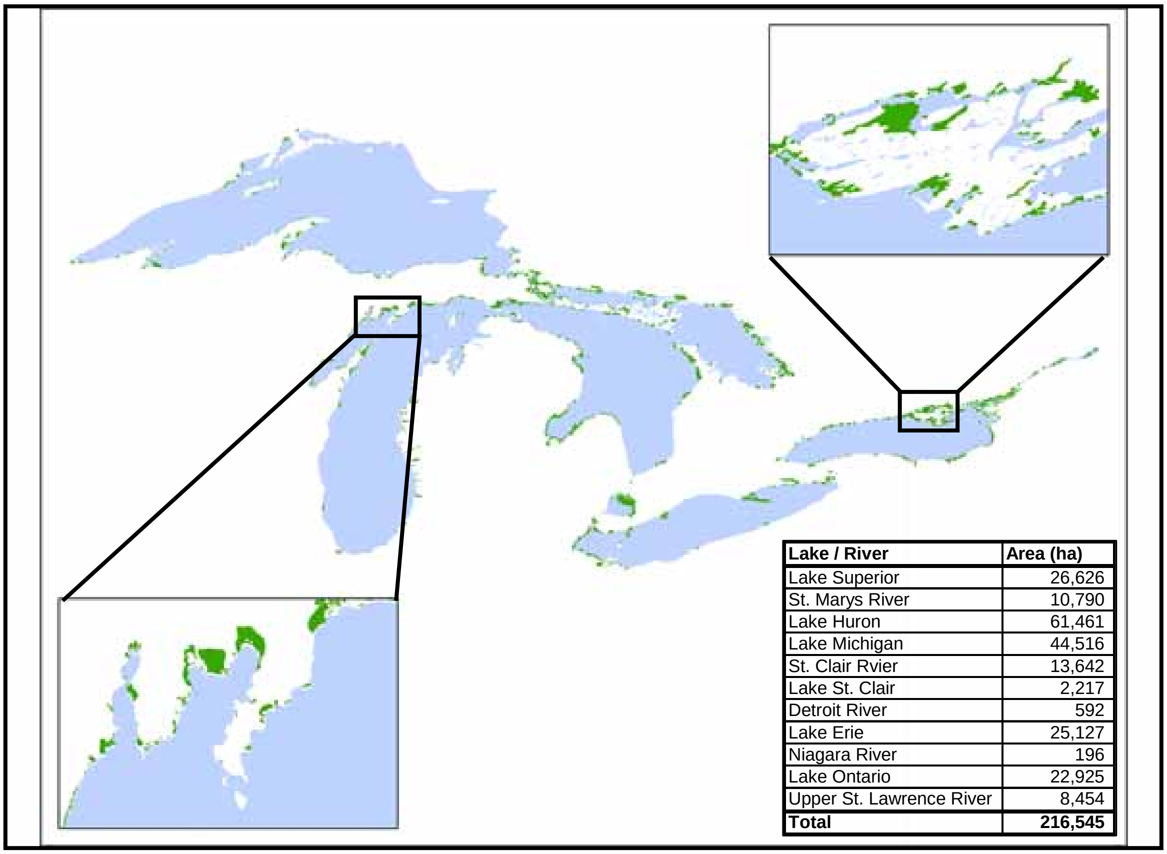

Lake / River	Area (ha)
Lake Superior	26,626
St. Marys River	10,790
Lake Huron	61,461
Lake Michigan	44,516
St. Clair Rvier	13,642
Lake St. Clair	2,217
Detroit River	592
Lake Erie	25,127
Niagara River	196
Lake Ontario	22,925
Upper St. Lawrence River	8,454
Total	**216,545**

Figure 1. Great Lakes coastal wetland distribution and total area by lake and river.
Source: Great Lakes Coastal Wetlands Consortium

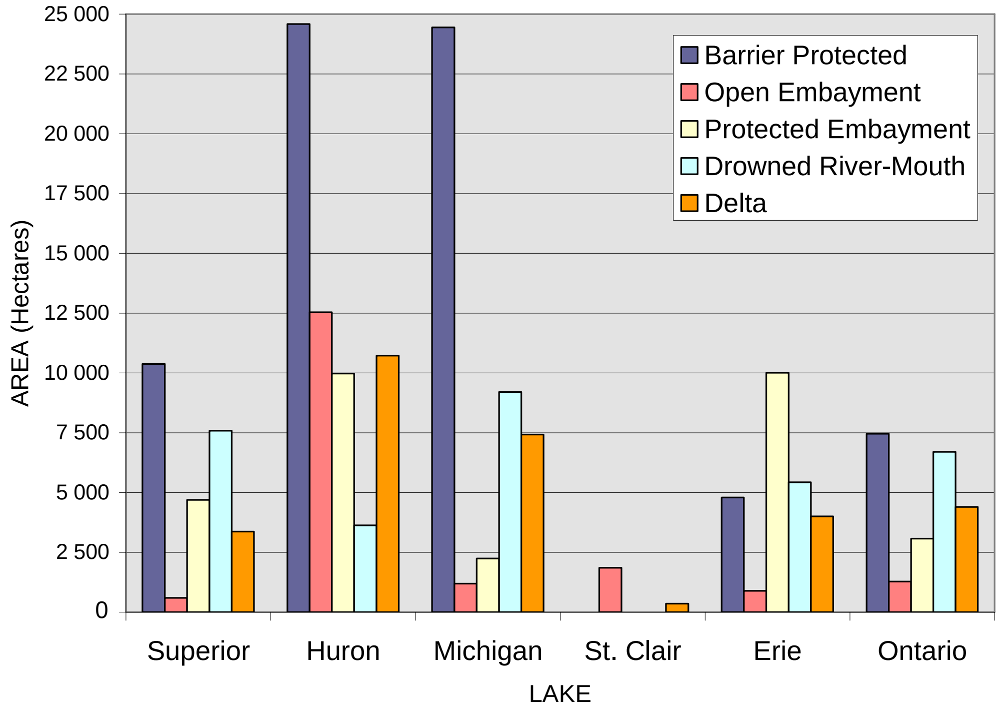

Figure 2. Coastal wetland area by geomorphic type within lakes of the Great Lakes system. Source: Great Lakes Coastal Wetlands Consortium

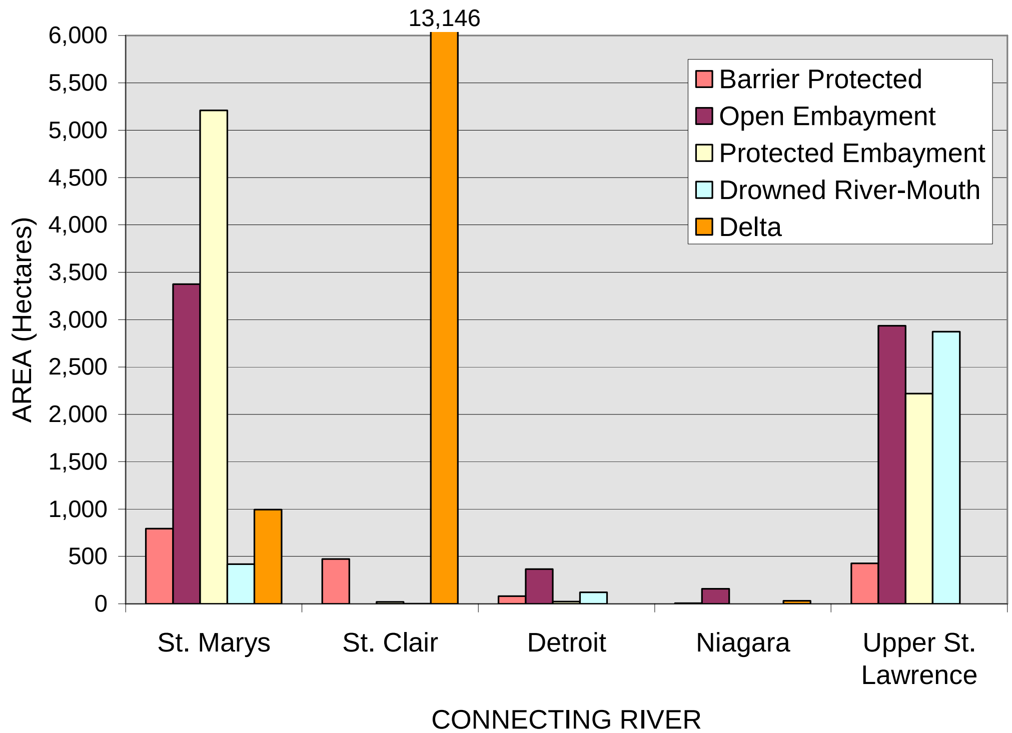

Figure 3. Coastal wetland area by geomorphic type within connecting rivers of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

Ice Duration on the Great Lakes
Indicator #4858

Overall Assessment
Status: **Mixed**
Trend: **Deteriorating (with respect to climate change)**

Purpose
•To assess the ice duration and thereby the temperature and accompanying physical changes to each lake over time, in order to infer the potential impact of climate change.

Ecosystem Objective
This indicator is used as a potential assessment of climate change, particularly within the Great Lakes basin. Changes in water and air temperatures will influence ice development on the Lakes and, in turn, affect coastal wetlands, nearshore aquatic environments, and inland environments.

State of the Ecosystem
Background
Air temperatures over a lake are one of the few factors that control the formation of ice on that surface. Colder winter temperatures increase the rate of heat released by the lake, thereby increasing the freezing rate of the water. Milder winter temperatures have a similar controlling effect, only the rate of heat released is slowed and the ice forms more slowly. Globally, some inland lakes appear to be freezing up at later dates, and breaking-up earlier, than the historical average, based on a study of 150 years of data (Magnuson et al. 2000). These trends add to the evidence that the earth has been in a period of global warming for at least the last 150 years.

The freezing and thawing of lakes is a very important aspect to many aquatic and terrestrial ecosystems. Many fish species rely on the ice to give their eggs protection against predators during the late part of the ice season. Nearshore ice has the ability to change the shoreline as it can encroach upon the land during winter freeze-up times. Even inland systems are affected by the amount of ice that forms, especially within the Great Lakes basin. Less ice on the Great Lakes allows for more water to evaporate and be spread across the basin in the form of snow. This can have an affect on the foraging animals (like deer), that need to dig through snow during the winter in order to obtain food.

Status of Ice Duration on the Great Lakes
Observations of the Great Lakes data showed no real conclusive trends with respect to the date of freeze-up or break-up. A reason for this could be that due to the sheer size of the Lakes, it wasn’t possible to observe the whole lake during the winter season (at least before satellite imagery), and therefore only regional observations were made (inner bays and ports). However, there was enough data collected from ice charts to make a statement concerning the overall ice cover during the season. There appears to be a decrease in the maximum ice cover per season over the last thirty years (Figure 1).

The trends on each of the five Lakes show that during this time span the maximum amount of ice forming each year has been decreasing, which, in-fact, can be correlated to the average ice cover per season observed for the same time duration (Table 1). Between the 1970s and 1990s there was at least a 10% decline in the maximum ice cover on each Lake, and almost as much as 18% in some cases, with the greatest decline occurring during the 1990s. Since a complete freeze-up did not occur on all the Great Lakes, a series of inland lakes (known to freeze every winter) in Ontario were examined to see if there was any similarity to the results in the previous studies. Data from Lake Nipissing and Lake Ramsey were plotted (Figure 2) based on the ice-on date (complete freeze-over date) and the break-up date (ice-off date). As it turns out, the freeze-up date for Lake Nipissing appears to have the same trend as the other global inland lakes: freezing over later in the year. Lake Ramsey however, seems to be freezing over earlier in the season. The ice-off date for both however, appear to be increasing, or occurring at later dates in the year. These results contradict what is said to be occurring with other such lakes in the Northern Hemisphere (see Magnuson et al. 2000).

The satellite data used in this analysis can be supplemented by on-the-ground citizen science collected data. The IceWatch program of Environment Canada's Ecological Monitoring and Assessment Network and Nature Canada have citizen scientists collecting ice-on and ice-off dates of lakes throughout the Ontario portion of the Great Lakes basin. These volunteers use the same criteria for ice-on and ice-off as does the satellite data, although the volunteers only collect data for the portion of the lake that is visible from a single vantage point on the shore. The IceWatch program began in 2000 as a continuation of a program run by the Meteorological Service of Canada. Data from this program date back to the 1850s. An analysis of data from this database and the Canadian Ice Database (Canadian Ice Services/Meteorological Service of Canada) showed that ice break-up dates were occurring approximately one day earlier every seven years between 1950 and 2004 for 341 lakes across Canada (Futter et al. 2006. *In press*). The data from IceWatch is not as comprehensive as the satellite collected data, but does show some trends in the Great Lakes basin. From two sites with almost 100 years of data, Lake Nipissing is shown to be thawing later in the season (Figure 3). IceWatch data from near Lake Ramsay indicate that lakes have been freezing later over the past thirty years.

Pressures
Based on the results of Figure 1 and Table 1, it seems that ice formation on the Great Lakes should continue to decrease in total cover if the predictions on global atmospheric warming are true. Milder winters will have a drastic effect on how much of the lakes are covered in ice, which in turn, will have an effect on many aquatic and terrestrial ecosystems that rely on lake ice for protection and food acquisition.

Management Implications
Only a small number of data sets were collected and analyzed for this study, so this report is not conclusive. To reach a level of significance that would be considered acceptable, more data on lake ice formation would have to be gathered. While the data for the Great Lakes is easily obtained from 1972-present, smaller inland lakes, which may be affected by climate change at a faster rate, should be examined. As much historical information that is available should be obtained. This data could come from IceWatch observers and the IceWatch database from throughout the Great Lakes basin. The more data that are received will increase the statistical significance of the results.

Acknowledgments
Author: Gregg Ferris, Environment Canada Intern, Downsview, ON.
Updated by: Heather Andrachuk, Environment Canada, Ecological Monitoring and Assessment Network (EMAN); Heather.Andrachuk@ec.gc.ca; (905)336-4411.
All data analyzed and charts created by the author.

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Ice charts obtained from the National Oceanic and Atmospheric Administration (NOAA) and the Canadian Ice Service (CIS).

Data for Lake Nipissing and Lake Ramsey obtained from Walter Skinner, Climate and Atmospheric Research, Environment Canada-Ontario Region.

Comments from the author

Increased winter and summer air temperatures appear to be the greatest influence on ice formation. Currently there are certain protocols, on a global scale, that are being introduced in order to reduce the emission of greenhouse gases.

It would be convenient for the results to be reported every four to five years (at least for the Great Lakes), and quite possibly a shorter time span for any new inland lake information. It may also be feasible to subdivide the Great Lakes into bays and inlets, etc., in order to get an understanding of what is occurring in nearshore environments.

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Figure 3. Ice-off dates and trend line from 1900-2000 on Lake Nipising.
Source: Ecological and Monitoring Assessment Network (EMAN)

Lake	1970 - 1979	1980 - 1989	1990 - 1999	Change from 1970s to 1990s
Erie	94.5	90.8	77.3	-17.2
Huron	71.3	71.7	61.3	-10.0
Michigan	50.2	45.6	32.4	-17.8
Ontario	39.8	29.7	28.1	-11.7
Superior	74.5	73.9	62.0	-12.6

Table 1. Mean ice coverage, in percent, during the corresponding decade.
Source: National Oceanic and Atmospheric Administration

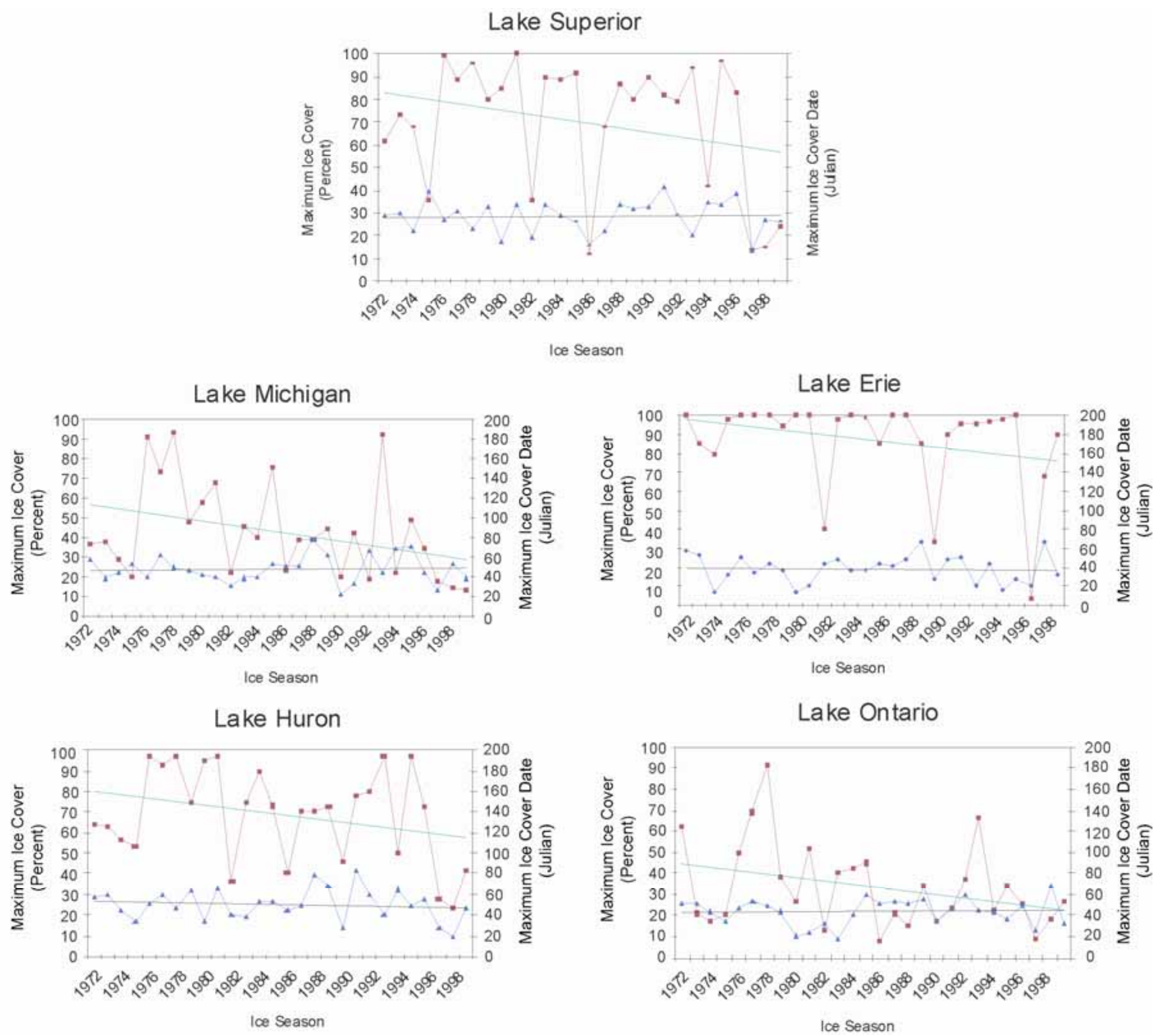

Figure 1. Trends of maximum ice cover and the corresponding date on the Great Lakes, 1972-2000. The red line represents the percentage of maximum ice cover and the blue line represents the date of maximum ice cover.
Source: National Oceanic and Atmospheric Administration

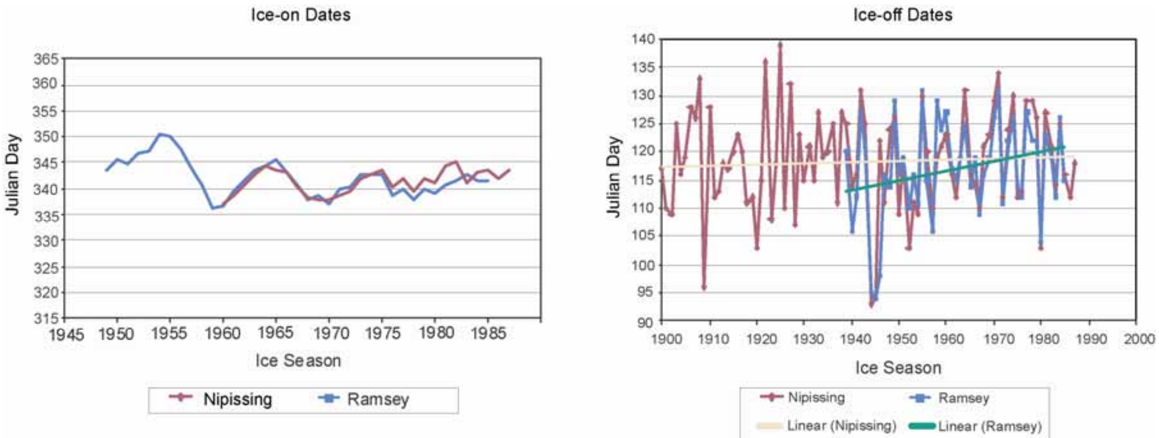

Figure 2. Ice-on and ice-off dates for Lake Nipissing (red line) and Lake Ramsey (blue line). Data were smoothed using a 5-year moving average.
Source: Climate and Atmospheric Research and Environment Canada

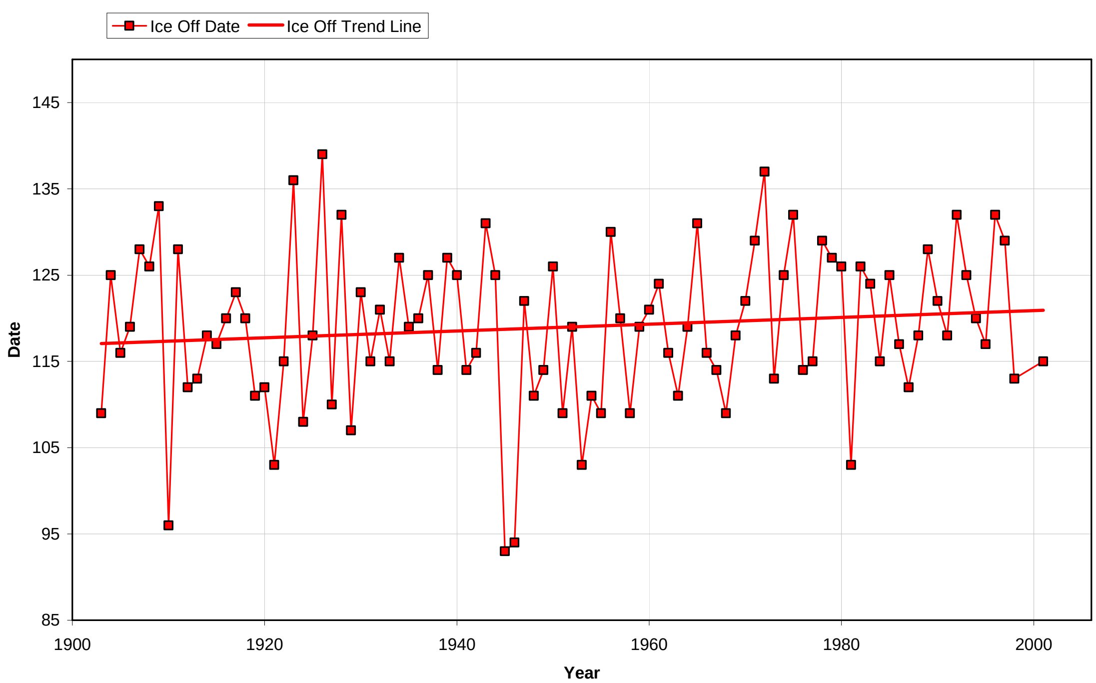

Figure 3. Ice-off dates and trend line from 1900-2000 on Lake Nipising.
Source: Ecological and Monitoring Assessment Network (EMAN)

Effect of Water Level Fluctuations

Indicator #4861

Assessment: Mixed, Trend Not Assessed

Data are available for water level fluctuations for all Lakes. A comparison of wetland vegetation along regulated Lake Ontario to vegetation along unregulated Lakes Michigan and Huron provides insight into the impacts of water level regulation.

Purpose

- To examine the historic water levels in all the Great Lakes, and compare these levels and their effects on wetlands with post-regulated levels in Lakes Superior and Ontario, where water levels have been regulated since about 1914 and 1959, respectively; and
- To examine water level fluctuation effects on wetland vegetation communities over time as well as aiding in the interpretation of estimates of coastal wetland area, especially in those Great Lakes for which water levels are not regulated.

Ecosystem Objective

The ecosystem objective is to maintain the diverse array of Great Lakes coastal wetlands by allowing, as closely as is possible, the natural seasonal and long-term fluctuations of Great Lakes water levels.

State of the Ecosystem

Background

Naturally fluctuating water levels are known to be essential for maintaining the ecological health of Great Lakes shoreline ecosystems, especially coastal wetlands. Thus, comparing the hydrology of the Lakes serves as an indicator of degradation caused by the artificial alteration of the naturally fluctuating hydrological cycle.

Great Lakes shoreline ecosystems are dependent upon natural disturbance processes, such as water level fluctuations, if they are to function as dynamic systems. Naturally fluctuating water levels create ever-changing conditions along the Great Lakes shoreline, and the biological communities that populate these coastal wetlands have responded to these dynamic changes with rich and diverse assemblages of species.

Status of Great Lakes Water Level Fluctuations

Water levels in the Great Lakes have been measured since 1860, but 140 years is a relatively short period of time when assessing the hydrological history of the Lakes. Sediment investigations conducted by Baedke and Thompson (2000) on the Lake Michigan-Huron system indicate quasi-periodic lake level fluctuations (Figure 1), both in period and amplitude, on an average of about 160 years, but ranging from 120-200 years. Within this 160-year period, there also appear to be sub-fluctuations of approximately 33 years. Therefore, to assess water level fluctuations, it is necessary to consider long-term data.

Because Lake Superior is at the upper end of the watershed, the fluctuations have less amplitude than the other lakes. Lake Ontario (Figure 2), at the lower end of the watershed, more clearly shows these quasi-periodic fluctuations and the almost

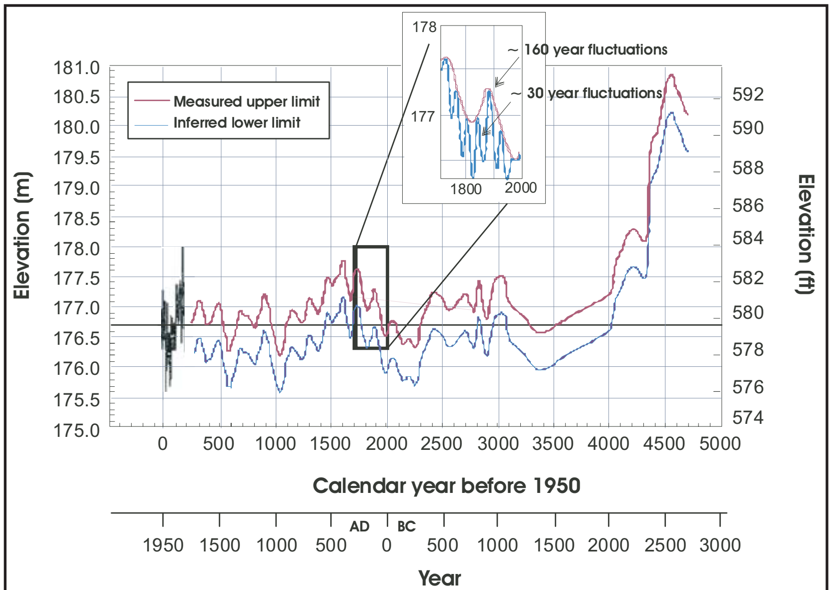

Figure 1. Sediment investigations on the Lake Michigan-Huron system indicates quasi-periodic lake level fluctuations.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

complete elimination of the high and low levels since the lake level began to be regulated in 1959, and more rigorously since 1976. For example, the 1986 high level that was observed in the other lakes was eliminated from Lake Ontario. The level in Lake Ontario after 1959 contrasts with that of the Lake Michigan-Huron system (Figure 3), which shows the more characteristic high and low water levels.

The significance of seasonal and long-term water level fluctuations on coastal wetlands is perhaps best explained in terms of the vegetation, which, in addition to its own diverse composition, provides the substrate, food, cover, and habitat for many other species dependent on coastal wetlands.

Seasonal water level fluctuations result in higher summer water levels and lower winter levels. Additionally, the often unstable summer water levels ensure a varied hydrology for the diverse plant species inhabiting coastal wetlands. Without the seasonal variation, the wetland zone would be much narrower and less diverse. Even very short-term fluctuations resulting from

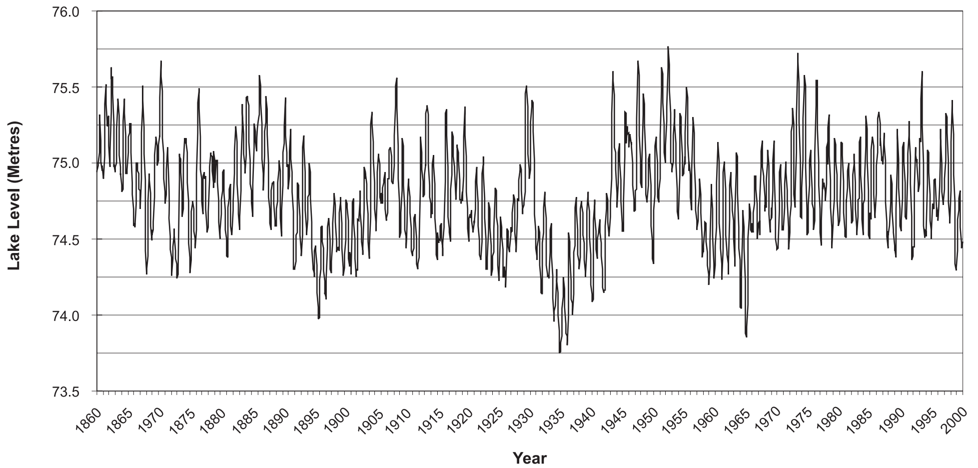

Figure 2. Actual water levels for Lake Ontario. IGLD-International Great Lakes Datum. Zero for IGLD is Rimouski, Quebec, at the mouth of the St. Lawrence River. Water level elevations in the Great Lakes/St. Lawrence River system are measured above water level at this site.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

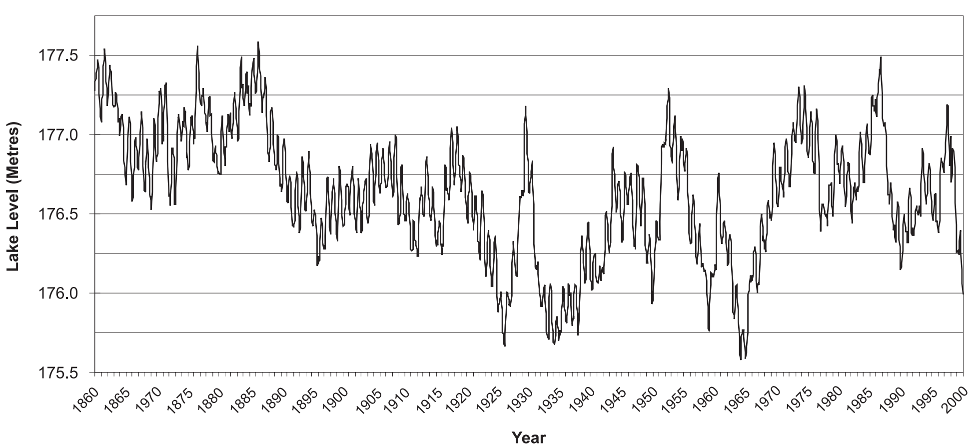

Figure 3. Actual water levels for Lakes Huron and Michigan. IGLD-International Great Lakes Datum. Zero for IGLD is Rimouski, Quebec, at the mouth of the St. Lawrence River. Water level elevations in the Great Lakes/St. Lawrence River system are measured above water level at this site.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

changes in wind direction and barometric pressure can substantially alter the area inundated, and thus, alter the coastal wetland community.

Long-term water level fluctuations, of course, have an impact over a longer period of time. During periods of high water, there is a die-off of shrubs, cattails, and other woody or emergent species that cannot tolerate long periods of increased depth of inundation. At the same time, there is an expansion of aquatic communities, notably submergents, into the newly inundated area. As the water levels recede, seeds buried in the sediments germinate and vegetate this newly exposed zone, while the aquatic communities recede out-ward back into the lake. During periods of low water, woody plants and emergents expand again to reclaim their former area as aquatic communities establish themselves further outward into the lake. The long-term high-low fluctuation puts natural stress on coastal wetlands, but is vital in maintaining wetland diversity. It is the mid-zone of coastal wetlands that harbors the greatest biodiversity. Under more stable water levels, coastal wetlands occupy narrower zones along the lakes and are considerably less diverse, as the more dominant species, such as cattails, take over to the detriment of those less able to compete under a stable water regime. This is characteristic of many of the coastal wetlands of Lake Ontario, where water levels are regulated.

Pressures

Future pressures on the ecosystem include additional withdrawals or diversions of water from the Lakes, or additional regulation of the high and low water levels. These potential future pressures will require direct human intervention to implement, and thus, with proper consideration of the impacts, can be prevented. The more insidious impact could be caused by global climate change. The quasi-periodic fluctuations of water levels are the result of climatic effects, and global warming has the potential to greatly alter the water levels in the Lakes.

Management Implications

The Lake Ontario-St. Lawrence River Study Board is undertaking a comprehensive 5-year study (2000-2005) for the International Joint Commission (IJC) to assess the current criteria used for regulating water levels on Lake Ontario and in the St. Lawrence River.
The overall goals of Environment/Wetlands Working Group of the IJC study are (1) to ensure that all types of native habitats

(floodplain, forested and shrubby swamps, wet meadows, shallow and deep marshes, submerged vegetation, mud flats, open water, and fast flowing water) and shoreline features (barrier beaches, sand bars/dunes, gravel/cobble shores, and islands) are represented in an abundance that allows for the maintenance of ecosystem resilience and integrity over all seasons, and (2) to maintain hydraulic and spatial connectivity of habitats to ensure that fauna have access, temporally and spatially, to a sufficient surface of all the types of habitats they need to complete their life cycles.

The environment/wetlands component of the IJC study provides a major opportunity to improve the understanding of past water-regulation impacts on coastal wetlands. The new knowledge will be used to develop and recommend water level regulation criteria with the specific objective of maintaining coastal wetland diversity and health. Also, continued monitoring of water levels in all of the Great Lakes is vital to understanding coastal wetland dynamics and the ability to assess wetland health on a large scale. Fluctuations in water levels are the driving force behind coastal wetland biodiversity and overall wetland health. Their effects on wetland ecosystems must be recognized and monitored throughout the Great Lakes basin in both regulated and unregulated lakes.

Acknowledgments
Author: Duane Heaton, U.S. Environmental Protection Agency, Great Lakes National Programs Office, Chicago, IL.

Much of the information and discussion presented in this summary is based on work conducted by the following: Douglas A. Wilcox, Ph.D. (U.S. Geological Survey / Biological Resources Division); Todd A. Thompson, Ph.D. (Indiana Geological Survey); Steve J. Baedke, Ph.D. (James Madison University).

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Authors' Commentary

Human-induced global climate change could be a major cause of lowered water levels in the Lakes in future years. Further study is needed on the impacts of water level fluctuations on other nearshore terrestrial communities. Also, an educated public is critical to ensuring wise decisions about the stewardship of the Great Lakes basin ecosystem are made, and better platforms to getting understandable information to the public are needed.

Last Updated

State of the Great Lakes 2003

Coastal Wetland Plant Community Health
Indicator #4862

Overall Assessment

Status:	**Mixed**
Trend:	**Undetermined**

Lake-by-Lake Assessment

Lake Superior

Status:	Good
Trend:	Unchanging
Primary Factors Determining Status and Trend	Degradation around major urban areas

Lake Michigan

Status:	Mixed
Trend:	Unchanging
Primary Factors Determining Status and Trend	High quality wetlands in north part of lake

Lake Huron

Status:	Mixed
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Plowing, raking, and mowing on Saginaw Bay wetlands during low water causing degradation. Northern wetlands high quality

Lake Erie

Status:	Mixed
Trend:	Unchanging
Primary Factors Determining Status and Trend	Generally poor on US shore with some restoration at Metzger marsh – Presque Isle, PA and Long Pt, Ontario high quality wetlands

Lake Ontario

Status:	Poor
Trend:	Unchanging
Primary Factors Determining Status and Trend	Degraded by nutrient loading and water level control. Some scattered Canadian wetlands of higher quality.

Purpose

•To assess the level of native vegetative diversity and cover for use as a surrogate measure of quality of coastal wetlands which are impacted by coastal manipulation or input of sediments.

Ecosystem Objective
Coastal wetlands throughout the Great Lakes basin should be dominated by native vegetation, with low numbers of invasive plant species that have low levels of coverage. (Great Lakes Water Quality Agreement, United States and Canada 1987).

State of the Ecosystem
Background
To understand the condition of the plant community in coastal wetlands it is necessary to understand the natural differences that occur in the plant community across the Great Lakes basin. The characteristic size and plant diversity of coastal wetlands vary by wetland type, lake, and latitude, due to differences in geomorphic and climatic conditions. Major factors will be described below.

Lake: The water chemistry and shoreline characteristics of each Great Lake differ, with Lake Superior being the most distinct due to its low alkalinity and prevalence of bedrock shoreline. Nutrient levels also increase in the lake basins further to the east, that is, in Lake Erie, Lake Ontario, and in the upper St. Lawrence River.

Geomorphic wetland type: There are several different types of wetland based on the geomorphology of the shoreline where the wetland forms. Each landform has its characteristic sediment, bottom profile, accumulation of organic material, and exposure to wave activity. These differences result in differences in plant zonation and breadth, as well as species composition. All coastal wetlands contain different zones (swamp, meadow, emergent, submergent), some of which may be typically absent in certain geomorphic wetland types. All Great Lakes wetlands have recently been classified and mapped (Albert et al. In Press).
http://glc.org/wetlands/inventory.html

Latitude: Latitudinal differences in temperature result in floristic differences between the southern and northern Great Lakes. Probably more important is the increased agricultural activity along the shoreline of the southern Great Lakes, resulting in increased sedimentation and non-native species introductions.

There are characteristics of coastal wetlands that make usage of plants as indicators difficult in certain conditions. Among these are:

Water level fluctuations: Great Lakes water levels fluctuate greatly from year to year. Either an increase or decrease in water level can result in changes in numbers of species or overall species composition in the entire wetland or in specific zones. Such a change makes it difficult to monitor change over time. Changes are great in two zones, the wet meadow where grasses and sedges may disappear in high water or new annuals may appear in low water, and in shallow emergent or submergent zones, where submergent and floating plants may disappear when water levels drop rapidly.

Lake-wide alterations: For the southern lakes, most wetlands have been dramatically altered by both intensive agriculture and urban development of the shoreline. For Lake Ontario, water level control has resulted in major changes to the flora. For both of these cases, it is difficult to identify base-line high quality wetlands for comparison to degraded wetlands.

There are several hundred species of plant that occur within coastal wetlands. To evaluate the status of a wetland using plants as indicators, several different plant metrics have been suggested. Several of these are discussed briefly here.

Native plant diversity: The number of native plant species in a wetland is considered by many as a useful indicator of wetland health. The overall diversity of a site tends to decrease from south to north. Different hydrogeomorphic wetland types support vastly different levels of native plant diversity, complicating the use of this metric.

Non-native species: Non-native species are considered signs of wetland degradation, typically responding to increased sediment, nutrients, physical disturbance, and seed source. The amount of non-native species coverage appears to be a more effective measure of degradation than number of non-native species, except in the most heavily degraded sites.

Submergent species: Submergent plants respond to high levels of sediment, nutrient enrichment, and turbidity, and plant species have been identified that respond to each of these changes. Floating species, such as Lemna spp., are similarly responsive to nutrient enrichment. While submergents are valuable indicators whose response to changing environmental conditions is well documented, they also respond dramatically to natural fluctuations in the water level, making them less dependable as indicators in the Great Lakes than in other wetland settings.

Nutrient responsive species: Several species from all plant zones are known to respond to nutrient enrichment. Cattails (Typha spp.) are the best known responders.

Salt tolerance: Many species are not tolerant to salt, which is introduced along major coastal highways. Narrow-leaved cattails are known to be very tolerant to high salt levels.

Floristic Quality Index (FQI): Many of the states and provinces along the Great Lakes have developed indices based on the “conservatism” of all plants growing there. A species is considered conservative if it only grows in a specific, high quality environment. FQI has proved effective for comparing similar wetland sites. However, FQI of a given wetland can change dramatically in response to a water level change, limiting its usefulness in monitoring the condition of a given wetland from year to year without development of careful sampling protocols. Another problem associated with FQIs is that the conservatism values for a given plant vary between states and provinces.

Status of Wetland Plant Community Health

The state of the wetland plant community is quite variable, ranging from good to poor across the Great Lakes basin. The wetlands in individual lake basins are often similar in their characteristics because of water level controls and lake-wide near-shore management practices. There is evidence that the plant component in some wetlands is deteriorating in response to extremely low water levels in some of the Great Lakes, but this deterioration is not seen in all wetlands within these lakes. In general, there is slow deterioration in many wetlands as shoreline alterations introduce non-native species. However, the turbidity of the southern Great Lakes has reduced with expansion of zebra mussels, resulting in improved submergent plant diversity in many wetlands.

Trends in wetland health based on plants have not been well established. In the southern Great Lakes (Lake Erie, Lake Ontario, and the Upper St. Lawrence River), almost all wetlands are degraded by either water level control, nutrient enrichment, sedimentation, or a combination of these factors. Probably the strongest demonstration of this is the prevalence of broad zones of cat-tails, reduced submergent diversity and coverage, and prevalence of non-native plants, including reed (Phragmites australis), reed canary grass (Phalaris arundinacea), purple loosestrife (Lythrum salicaria), curly pondweed (Potamogeton crispus), Eurasian milfoil (Myriophyllum spicatum), and frog bit (Hydrocharis morsus-ranae). In the remaining Great Lakes (Lake St. Clair, Lake Huron, Lake Michigan, Georgian Bay, Lake Superior, and their connecting rivers), intact, diverse wetlands can be found for most geomorphic wetland types. However, low water conditions have resulted in the almost explosive expansion of reed in many wetlands, especially in Lake St. Clair and southern Lake Huron, including Saginaw Bay. As water levels rise, the response of reed should be monitored.

One of the disturbing trends is the expansion of frog bit, a floating plant that forms dense mats capable of eliminating submergent plants, from the St. Lawrence River and Lake Ontario westward into Lake Erie. This expansion will probably continue into all or many of the remaining Great Lakes.

Studies in the northern Great Lakes have demonstrated that non-native species like reed, reed canary grass, and purple loosestrife have established throughout the Great Lakes, but that the abundance of these species is low, often restricted to only local disturbances such as docks and boat channels. It appears that undisturbed marshes are not easily colonized by these species. However, as these species become locally established, seeds or fragments of plant may be able to establish when water level changes create appropriate sediment conditions.

Pressures

There are several pressures that lead to degradation of coastal wetlands.

Agriculture: Agriculture degrades wetlands in several ways, including nutrient enrichment from fertilizers, increased sediments from erosion, increased rapid runoff from drainage ditches, introduction of agricultural non-native species (reed canary grass), destruction of inland wet meadow zone by plowing and diking, and addition of herbicides. In the southern lakes, Saginaw Bay, and Green Bay, agricultural sediments have resulted in highly turbid waters which support few or no submergent plants.

Urban development: Urban development degrades wetlands by hardening shoreline, filling wetland, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increased nutrient loading from sewage treatment plants. In most urban settings almost complete wetland loss has occurred along the shoreline.

Residential shoreline development: Along many coastal wetlands, residential development has altered wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. While less intensive than either agriculture or urban development, local physical alteration often results in introduction of non-native species. Shoreline hardening can completely eliminate wetland vegetation.

Mechanical alteration of shoreline: Mechanical alteration takes a diversity of forms, including diking, ditching, dredging, filling, and shoreline hardening. With all of these alterations non-native species are introduced by construction equipment or in introduced sediments. Changes in shoreline gradients and sediment conditions are often adequate to allow non-native species to become established.

Introduction of non-native species: Non-native species are introduced in many ways. Some were purposefully introduced as agricultural crops or ornamentals, later colonizing in native landscapes. Others came in as weeds in agricultural seed. Increased sediment and nutrient enrichment allows many of our worst aquatic weeds to out-compete native species. Most of our worst non-native species are either prolific seed producers or reproduce from fragments of root or rhizome. Non-native animals have also been responsible for increased degradation of coastal wetlands. One of the worst invasive species has been Asian carp, who's mating and feeding result in loss of submergent vegetation in shallow marsh waters.

Management Implications

While plants are currently being evaluated as indicators of specific types of degradation, there are limited examples of the effects of changing management on plant composition. Restoration efforts at Coots Paradise, Oshawa Second, and Metzgers marsh have recently evaluated a number of restoration approaches to restore submergent and emergent marsh vegetation, including carp elimination, hydrologic restoration, sediment control, and plant introduction. The effect of agriculture and urban sediments may be reduced by incorporating buffer strips along streams and drains. Nutrient enrichment could be reduced by more effective fertilizer application, reducing algal blooms. However, even slight levels of nutrient enrichment cause dramatic increases in submergent plant coverage. For most urban areas it may prove impossible to reduce nutrient loads adequately to restore native aquatic vegetation. Mechanical disturbance of coastal sediments appears to be one of the primary vectors for introduction of non-native species. Thorough cleaning of equipment to eliminate seed source and monitoring following disturbances might reduce new introductions of non-native plants.

Acknowledgments

Authors: Dennis Albert, Michigan Natural Features Inventory, Michigan State University Extension.

Contributors: Great Lakes Coastal Wetlands Consortium

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Land Cover Adjacent to Coastal Wetlands

Indicator # 4863

Overall Assessment

Status:	Not Fully Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	The status and trends are currently under investigation and proposed for additional investigation for the full basin (see Data Sources). Although other results exist for Canada (see Data Sources), “Land Cover Adjacent to Coastal Wetlands” results are currently unavailable for Canada.

Lake-by-Lake Assessment

Lake Superior

Status:	Not Fully Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	The status and trends are currently under investigation and proposed for additional investigation in the Lake Superior Basin (see Data Sources)

Lake Michigan

Status:	Not Fully Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	The status and trends are currently under investigation and proposed for additional investigation in the Lake Michigan Basin (see Data Sources)

Lake Huron

Status:	Not Fully Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	The status and trends are currently under investigation and proposed for additional investigation in the Lake Huron Basin (see Data Sources)

Lake Erie

Status:	Not Fully Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	The status and trends are currently under investigation and proposed for additional investigation in the Lake Erie Basin (see Data Sources)

Lake Ontario

Status:	Not Fully Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	The status and trends are currently under investigation and proposed for additional investigation in the Lake Ontario Basin (see Data Sources)

Purpose
Assess the basin-wide presence, location, and/or spatial extent of land cover in close proximity to coastal wetlands. Infer the condition of coastal wetlands as a function of adjacent land cover. Relevant coastal areas in the Great Lakes Basin have been mapped to assess the presence and proximity of general land cover in the vicinity of wetlands using satellite remote-sensing data and geographic information systems (GIS), providing a broad scale measure of land cover in the context of habitat suitability and habitat vulnerability for a variety of plant and animal species. For example, upland grassland and/or upland forest areas adjacent to wetlands may be important areas for forage, cover, or reproduction for organisms. Depending upon the particular physiological and sociobiological requirements of the different organisms, the wetland-adjacent land cover extent (e.g., the width or total area of the upland area around the wetland) may be used to describe the potential for suitable habitat, or the vulnerability of these areas of habitat to loss or degradation. Although other SOLEC Indicators are described for Canada (see Data Sources) at a broad scale, basin-wide "Land Cover Adjacent to Coastal Wetlands" results are currently unavailable for Canada.

Ecosystem Objective
Restore and maintain the ecological (i.e., hydrologic and biogeochemical) functions of Great Lakes coastal wetlands. Presence, wetland-proximity, and/or spatial extent of land cover should be such that the hydrologic and biogeochemical functions of wetlands continue.

State of the Ecosystem
The state of the Great Lakes Ecosystem (i.e., the sum of ecological functions for the full Great Lakes Basin) is currently under investigation and proposed for additional investigation (see Data Sources). Differences in the regional status of "Habitat Adjacent to Coastal Wetlands" can be determined using the existing data (see Pressures), but the results are preliminary and observations are not conclusive. Nor can the regional trends be extrapolated to determine the state of the ecosystem as a whole.

Percent forest adjacent to wetlands
The amount of forest land cover on the periphery of wetlands may indicate the amount of upland wooded habitat for organisms that may travel relatively short distances to and from nearby forested areas and wetland areas for breeding, water, forage, or shelter. Also, the affects of runoff on wetlands from nearby areas (e.g., nearby agricultural land) may be ameliorated by biogeochemical processes that occur in the forests on the periphery of the wetland. For example, forest vegetation may contribute to the uptake, accumulation, and transformation of chemical constituents in runoff. Broad-scale approaches to assessing percentage of forest directly adjacent to wetlands may be calculated by summing the total area of forest land cover directly adjacent to wetland regions in a reporting unit (e.g., an Ecoregion, a watershed, or a state) and dividing by wetland total area in the reporting unit. This calculation ignores those upland areas of forest outside of the adjacent "buffer zone" for wetlands within each reporting unit. Other buffer distances may be appropriate for other habitat analyses, depending on the type of organism; for runoff analyses the chemical constituent(s), flow dynamics, soil conditions, position of wetland in the landscape, and other landscape characteristics should be carefully considered. Coastal wetland areas may be generally assessed by calculating forest wetland-adjacency in specifically targeted

coastal wetlands of interest, by targeting narrow coastal areas such as areas within 1 km of the lake shoreline (Figure 1), or by targeting all wetlands in a specific inland and coastal region of the historical lake plain (Figure 2).

Percent grassland adjacent to wetlands
The amount of grassland on the periphery of wetlands may indicate the amount of upland herbaceous plant habitat for organisms that might travel relatively short distances to and from nearby upland grassland and wetland areas for breeding, water, forage, or shelter. As with forested areas, the affect of runoff on wetlands from areas nearby (e.g., agricultural) land may be ameliorated by biogeochemical processes that occur in herbaceous areas that are on the periphery of the wetland. For example, herbaceous vegetation stabilizes soils and may reduce erosional soil loss to nearby wetlands and other surface water bodies. As with forest calculations, broad-scale approaches to assessing percentage of grassland directly adjacent to wetlands may be calculated by summing the total area of grassland directly adjacent to wetland regions in a reporting unit. Other buffer distances may be more appropriate for habitat analyses, depending on the type of organism; for runoff analyses the chemical constituent(s), flow dynamics, soil conditions, position of wetland in the landscape, and other landscape characteristics should be carefully considered. Coastal wetland areas may be generally assessed by calculating grassland wetland-adjacency in specifically targeted coastal wetlands of interest; by targeting narrow coastal areas such as areas within 1 km of the lake shoreline (Figure 3), or by targeting all wetlands in a specific inland and coastal region of the historical lake plain (Figure 4).

Standard Deviation
Classes describe the distribution of percentage of forest or percentage of grassland adjacent to wetlands (among reporting units) relative to the mean value for the metric distribution. Class breaks are generated by successively described by standard deviations from the mean value for the metric. A two-color ramp (red to blue) emphasizes values (above to below) the mean value for a metric, and is a useful method for visualizing spatial variability of a metric.

Pressures
Although several causal relationships have been postulated for changes in "Land Cover Adjacent to Coastal Wetlands" for the Great Lakes Basin (see Data Sources), it is undetermined as to the relative contribution of the various factors. However, some preliminary regional trends exist. For example, in the 1 km coastal region of southern Lake Superior there is a relatively high percent of forest adjacent to coastal wetlands, and in the 1 km coastal region of western Lake Michigan there is a relatively low percent of forest adjacent to coastal wetlands. Differences in percent forest between these two coastal zones generally track with respect to percent of agricultural land cover or urban land cover, as measured with similar techniques (see Data Sources). These results are preliminary and observations are not conclusive. Similar phenomena are currently under investigation and proposed for additional regional and full-basin investigation.

Management Implications
Because critical forest and grassland habitat areas on the periphery of coastal wetlands may influence the presence and fitness of localized and migratory organisms in the Great Lakes, natural resource managers may use these data to determine the ranking of their areas of interest, such as areas where they are responsible for coastal wetland resources, among other areas in the Great Lakes. It is important for managers to understand that results for their areas of interest are

reported among a distribution for the entire Great Lakes Basin (USA) and that caution should be used when interpreting the results at finer scales.

Comments from the author(s)

To conduct such measures at a broad scale, the relationships between wetland-adjacent land cover and the functions of coastal wetlands need to be verified. This measure will need to be validated fully with thorough field sampling data and sufficient a priori knowledge of such endpoints and the mechanisms of impact. The development of indicators (e.g., a regression model using adjacent vegetation characteristics and wetland hydroperiod) is an important goal, and requires uniform measurement of field parameters across a vast geographic region to determine accurate information to calibrate such models.

Acknowledgments

Authors: Ricardo D. Lopez, U.S. Environmental Protection Agency, National Exposure Research Laboratory, Environmental Sciences Division, Landscape Ecology Branch, Las Vegas, Nevada, USA

Data Sources

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Citation/Source

Lopez, R.D., D.T. Heggem, J.P. Schneider, R. Van Remortel, E. Evanson, L.A. Bice, D.W. Ebert, J.G. Lyon, and R.W. Maichle. 2005. The Great Lakes Basin Landscape Ecology Metric Browser (v2.0). EPA/600/C-05/011. The United States Environmental Protection Agency, Washington, D.C. Compact Disk and Online at http://www.epa.gov/nerlesd1/land-sci/glb_browser/GLB_Landscape_Ecology_Metric_Browser.htm

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Figure 1. Percent forest adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 1 km of shoreline; data are reported as standard deviations from the mean.
Source: Lopez *et al.*, 2006

Figure 2. Percent forest adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 5 km of shoreline; data are reported as standard deviations from the mean.
Source: Lopez *et al.*, 2006

Figure 3. Percent grassland adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 1 km of shoreline; data are reported as standard deviations from the mean.

Source: Lopez *et al.*, 2006

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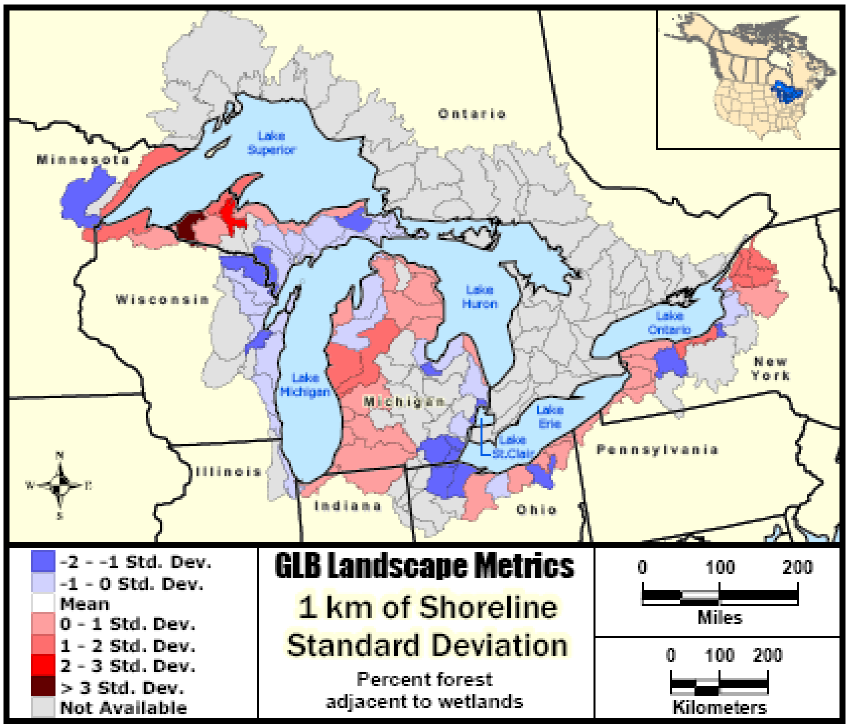
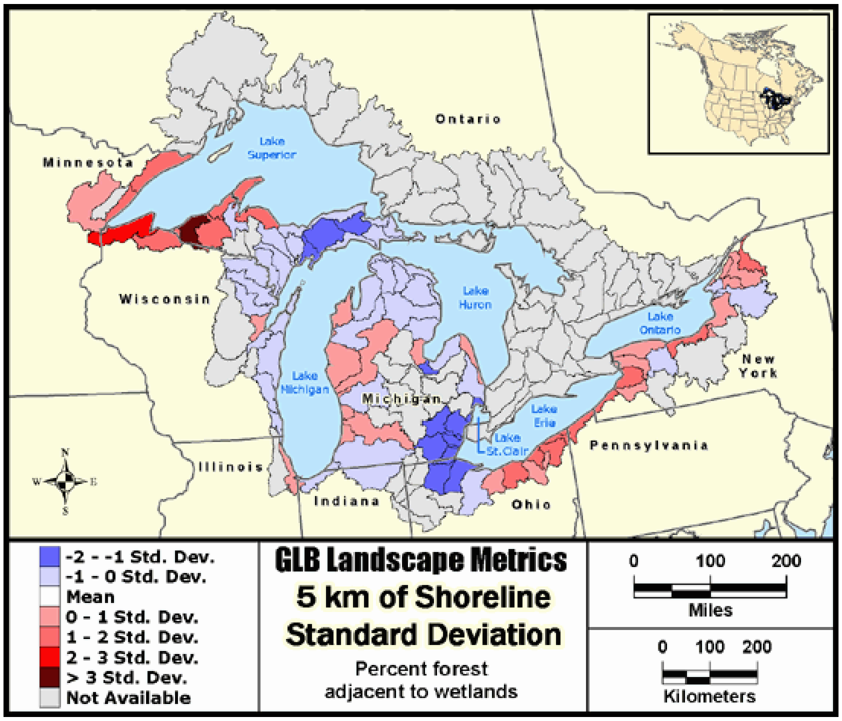


Figure 1. Percent forest adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 1 km of shoreline; data are reported as standard deviations from the mean.
Source: Lopez *et al.*, 2006



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Source: Lopez *et al.*, 2006

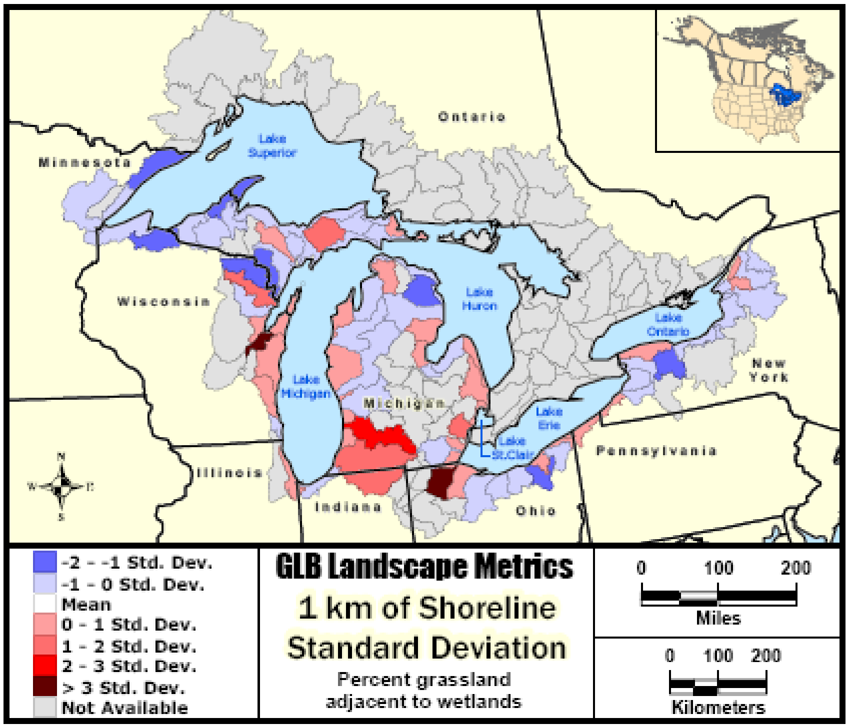

Figure 3. Percent grassland adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 1 km of shoreline; data are reported as standard deviations from the mean
Source: Lopez *et al.*, 2006

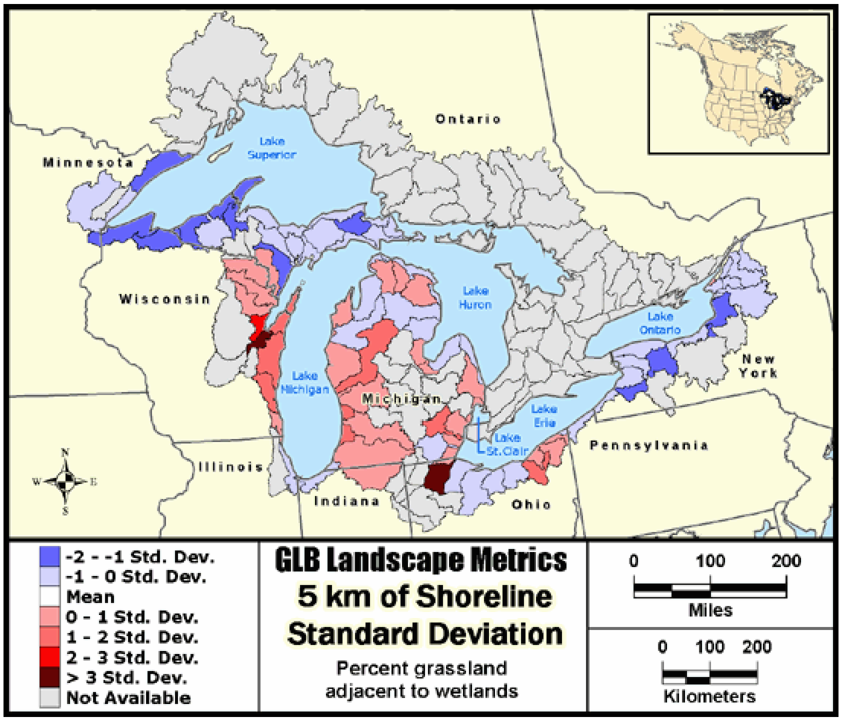

Figure 4. Percent grassland adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 5 km of shoreline; data are reported as standard deviations from the mean (Lopez *et al.*, 2006).

Urban Density
Indicator #7000

Overall Assessment

Status: **Mixed/ Trend Not Assessed**
Trend: **Improving, Unchanging, Deteriorating or Undetermined**
Primary Factors Determining Status and Trend

Lake by Lake Assessment
Trends on a lake-to-lake basis are unavailable due to insufficient data.

Purpose
To assess the urban human population density in the Great Lakes basin, and to infer the degree of land use efficiency for urban communities in the Great Lakes ecosystem.

Ecosystem Objective
Socio-economic viability and sustainable development are the generally acceptable goals for urban growth in the Great Lakes basin. Socio-economic viability indicates that development should be sufficiently profitable and social benefits are maintained over the long term. Sustainable development requires that we plan our cities to grow in a way so that they will be environmentally sensitive, and not compromise the environment for future generations. Thus, by increasing the densities in urban areas while maintaining low densities in rural and fringe areas, the amount of land consumed by urban sprawl will be reduced.

State of the Ecosystem
Background
Urban density is defined as the number of people per square kilometer of land for urban use in a municipal or township boundary. Low urban density indicates urban sprawl that is low-density development beyond the edge of service and employment, which separates residential areas from commercial, educational, and recreational areas - thus requiring automobiles for transportation (TCRP, 1998; TCRP, 2003; Neill et al. 2003). Urban sprawl has many detrimental effects on the environment. This process consumes large quantities of land, multiplies the required infrastructure, and increases the use of personal vehicles as the feasibility of alternate transportation declines. When there is an increased dependency on personal vehicles, consequentially, there is an increased demand for roads and highways, which in turn, produce segregated land uses, large parking lots, and urban sprawl. These implications result in the increased consumption of many non-renewable resources, the creation of impervious surfaces and damaged natural habitats, and the production of many harmful emissions. Segregated land use also lowers the quality of life as the average time spent traveling increases and the sense of community diminishes. For this assessment, the population data used was derived from 1990-2000 U.S. census and 1996 - 2001 Canadian census.

This indicator offers information on the presence, location, and predominance of human-built land cover and implies the intensity of human activity in the urban area. It may provide information about how such land cover types affect the ecological characteristics and functions of ecosystems, as demonstrated by the use of remote-sensing data and field observations.

Status of Urban Density

Within the Great Lakes basin there are 10 Census Metropolitan Areas (CMAs) in Ontario and 24 Metropolitan Statistical Areas (MSAs) in the United States. In Canada, a CMA is defined as an area consisting of one or more adjacent municipalities situated around a major urban core with a population of at least 100,000. In the United States, an MSA must have at least one urbanized area of 50,000 or more inhabitants and at least one urban cluster of at least a population of 10,000 but less than 50,000. The urban population growth in the Great Lakes basin show consistent patterns in both the United States and Canada. The population in both countries has been increasing over the past five to ten years. According to the 2001 Statistics Canada report, between 1996 and 2001, the population of the Great Lakes basin CMAs grew from 7,041,985 to 7,597,260, an increase of 555,275 or 7.9% in five years. The 2000 U.S. census reports that from 1990 to 2000 the population contained in the MSAs of the Great Lakes basin grew from 26,069,654 to 28,048,813, an increase of 1,979,159 or 7.6% in 10 years.

In the Great Lakes basin, as there has been an increase in population, there has also been an increase in the average population densities of the CMAs and MSAs. However, using the CMA or MSA as urban delineation has two major limitations. First, CMA and MSA contain substantial land areas that is rural and by themselves result in over-estimation of the land area occupied by a city or town. Second, these area delineations are based on a population density threshold and hence provide information on residential distribution and not necessarily on other urban land categories such as commercial land, recreational land. If within the CMAs and MSAs the amount of land being developed is escalating at a greater rate than the population growth rate, the average amount of developed land per person is increasing. For example, “In the GTA (Greater Toronto Area) during the 1960s, the average amount of developed land per person was a modest 0.019 hectares. By 2001 that amount tripled to 0.058 hectares per person” (Gilbert et al. 2001).

Population densities illustrate the development patterns of an area. If an urban area has a low population density this indicates that the city has taken on a pattern of urban sprawl and segregated land uses. This conclusion can be made as there is a greater amount of land per person; however, it is important to not only look at the overall urban density of an area, but also the urban dispersion. For example, a CMA or MSA with a relatively low density could have different dispersion characteristics than another CMA or MSA with the same density. One CMA or MSA could have the distribution of people centred around an urban core, while another could have a generally consistent sparse dispersion across the entire area and both would have the same average density. Therefore, to properly evaluate the growth pattern of an area, it is necessary to examine not only at the urban density but also at the urban dispersion.

While density is a readily understandable measure, it is challenging to quantify because of the difficulty in estimating true urban extent in a consistent and unbiased way. The geographic extents of MSAs and CMAs give approximate indications of relative city size, however, they tend to contain substantial areas of rural land use. Recently satellite remote sensing data has been used to map landuse of Canadian cities as part of a program to develop an integrated urban database, the Canadian Urban Land Use Survey (CUrLUS). In southern Ontario a total of 11 cities have been mapped using Landsat data acquired in the 1999-2002 timeframe and densities estimated using population statistics from the 2001 Canadian census (Figure 1). Population density is related with the city size. Bigger cities with higher population pressure have higher population density and more efficient land use. Comparing the population densities of 11 cities (or CMAs) in southern Ontario, derived from remote sensing mapping and 2001 census (Zhang and Guindon, 2005), the Great Toronto Area (GTA) has a higher population density (2848 km^{-2}) than other smaller cities.

The growth characteristics of 5 large Canadian cities have also been studied for the period 1986-2000. Preliminary analyses (Figure 2) indicate that the areal extents of these communities have grown at a faster rate than their populations and thus that sprawl continues to be a major problem.

A comparison of the ten CMAs and MSAs with the highest densities to the ten CMAs and MSAs with the lowest densities in the Great Lakes basin shows there is a large range between the higher densities and lower densities. Three of the ten lowest density areas have experienced a population decline while the others have experienced very little population growth over the time period examined. The areas with population declines and areas of little growth are generally occurring in northern parts of Ontario and eastern New York State. Both of these areas have had relatively high unemployment rates (between 8% and 12%) which could be linked to the slow growth and decreasing populations.

Overall, the growing urban areas in the Great Lakes basin seem to be increasing their geographical area at a faster rate than their population. This trend has many detrimental effects as outlined previously, namely urban sprawl and its implications. Such trends may continue to threaten the Great Lakes basin ecosystem unless this pattern is reversed. However, there is a need for a solid definitive information about relying on relatively fine-scale urban delineation data as it pertains to broad-scale trends for the Great Lakes region.

Pressures

Under the pressure of rapid population growth in the Great Lakes region, mostly in the metropolitan cities, the urban development has been undergoing unprecedented growth. For instance, the urban built-up area of the Greater Toronto Area (GTA) has been doubled since 1960s. Sprawl is increasingly becoming a problem in rural and urban fringe areas of the Great Lakes basin, placing a strain on infrastructure and consuming habitat in areas that tend to have healthier environments than those that remain in urban areas. This trend is expected to continue, which will exacerbate other problems, such as increased consumption of fossil fuels, longer commute times from residential to work areas, and fragmentation of habitat. For example, at current rates in Ontario, residential building projects will consume some 1,000 square kilometres of the province’s countryside, an area double the size of Metro Toronto, by 2031. Also, gridlock could add 45% to commuting times, and air quality could suffer due to a 40% increase in vehicle emissions (Loten 2004). The pressure urban sprawl exerts on the ecosystem has not yet been fully understood. It may be years before all of the implications have been realized.

Management Implications

Urban density impacts can be more thoroughly explored and explained if they are linked to the functions of ecosystems (e.g., as it relates to surface water quality). For this reason, interpretation of this indicator is correlated with many other Great Lakes indicators and their patterns across the Great Lakes. Urban density impacts on ecosystem functions should be linked to the ecological endpoint of interest, and this interpretation may vary as a result of the specificity of land cover type and the contemporaneous nature of the data. Thus, more detailed land cover specificity is required.

To conduct such measures at a broad scale, the relationships between land cover and ecosystem functions need to be verified. This measure will need to be validated fully with thorough field-sampling data and sufficient *a priori* knowledge of such endpoints and the mechanisms of impact (if applicable). The development of indicators (e.g., a regression model) is an important goal, and requires uniform measurement of field parameters across a vast geographic region to determine accurate information to calibrate such models.

The governments of the United States and Canada have both been making efforts to ease the strain caused by pressures of urban sprawl by proposing policies and creating strategies. Although this is the starting point in implementing a feasible plan to deal with the environmental and social pressures of urban sprawl, it does not suffice. Policies are not effective until they are put into practice and in the meantime our cities continue to grow at unsustainable rates. In order to mitigate the pressures of urban sprawl, a complete set of policies, zoning bylaws and redevelopment incentives must be developed, reviewed and implemented. As noted in the Urban Density indicator report from 2000, policies that encourage infill and brownfields redevelopment within urbanized areas will reduce sprawl. Compact development could save 20% in infrastructure costs (Loten 2004). Comprehensive land use planning that incorporates "green" features, such as cluster development and greenway areas, will help to alleviate the pressure from development.

For urban sustainable development, we should understand fully the potential negative impacts of urban high density development. High urban density indicates intensified human activity in the urban area, which would be potential threads to the urban environment quality. Therefore, the urbanization strategies should be based on the concept of sustainable development on the balance the costs and benefits.

Comments from the author(s)
A thorough field-sampling protocol, properly validated geographic information, and other remote-sensing-based data could lead to successful development of urban density as an indicator of ecosystem function and ecological vulnerability in the Great Lakes basin. This indicator could be applied to select sites, but would be most effective if used at a regional or basin-wide scale. Displaying U.S. and Canadian census population density on a GIS map will allow increasing sprawl to be documented over time in the Great Lakes basin on a variety of scales. For example, the maps included with the 2003 Urban Density report show the entire Lake Superior basin and a closer view of the southwestern part of the basin.

To best quantify the indicator for the whole Great Lakes watershed, a watershed-wide consistent urban built-up database is needed.

Acknowledgments
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Bert Guindon, Natural Resources Canada, Ottawa, ON;
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Lindsay Silk, Environment Canada Intern, Downsview, ON; and
Ying Zhang, Natural Resources Canada, Ottawa, ON.

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Figure 2. Growth characterization of 5 urban areas in the period of 1986-2001.

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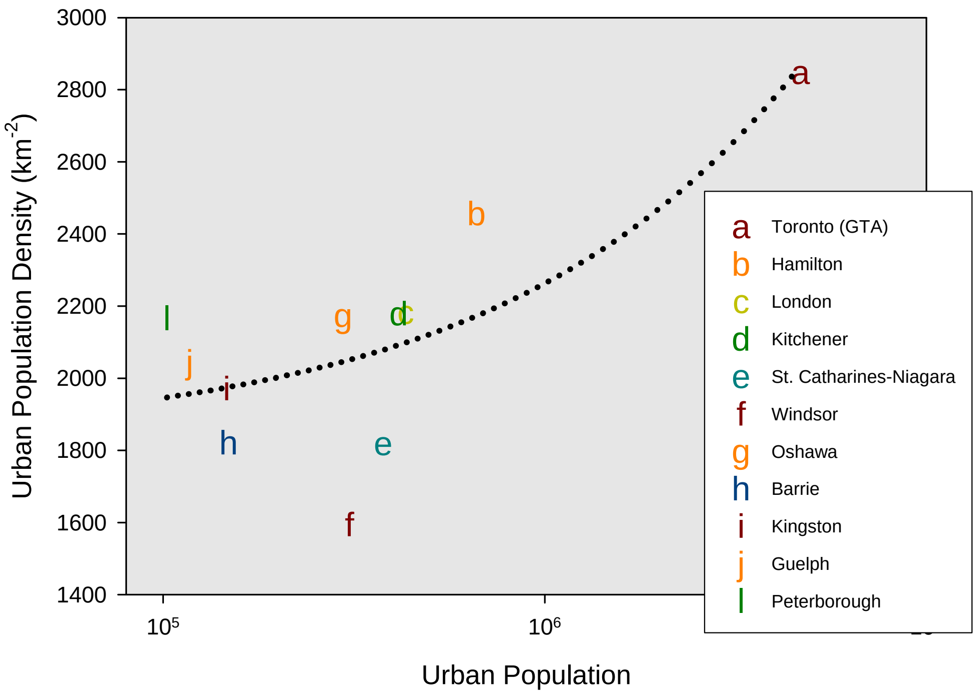

Figure 1. Population densities of cities with population more than 100,000 in southern Ontario of the Great Lakes watershed for 2001. Source: 'Y. Zhang and B. Guindon, private communication'

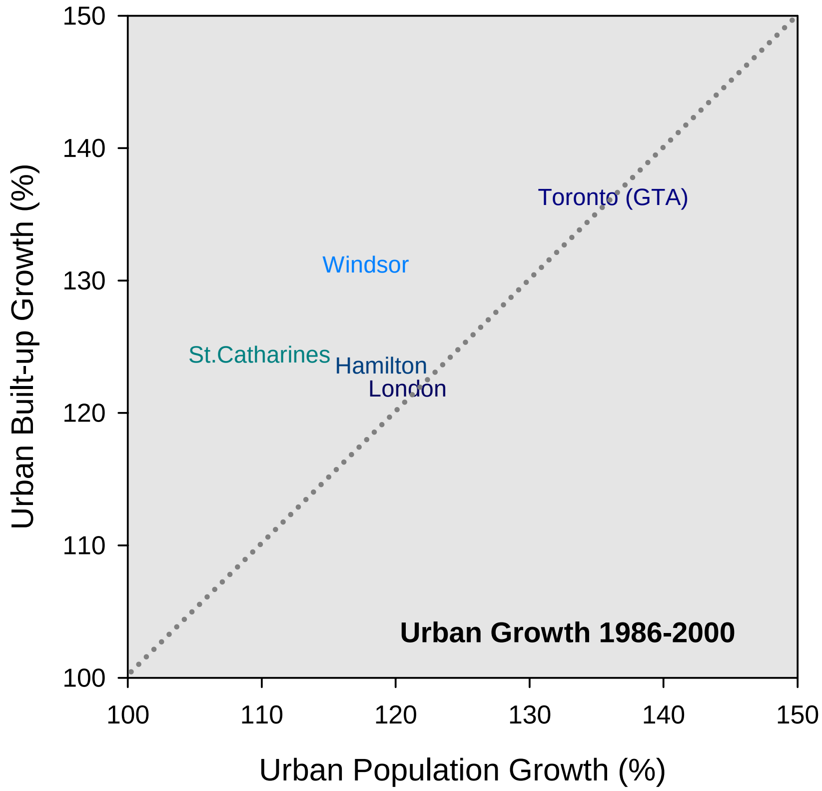

Figure 2. Growth characterization of 5 urban areas in the period of 1986-2001. Source: 'Y. Zhang and B. Guindon, private communication'

Land Cover/Land Conversion
Indicator #7002

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Primary Factors Determining Status and Trend: Low-intensity development increased 33.5%, road area increased 7.5%, and forest decreased 2.3% from 1992 and 2001. Agriculture lost 210,000 ha of land to development. Approximately 50% of forest losses were due to management and 50% to development.

Lake-by-Lake Assessment

Lake Superior

Status: Good
Trend: Undetermined
Primary Factors Determining Status and Trend: Lowest conversion rate of non-developed land to development and highest conversion rate of non-forest to forest. Of the 4.2 million ha watershed area on the U.S. side, 1,676 ha of wetland, 2,641 ha of agricultural land, and 14,300 ha of forest land were developed between 1992 and 2001.

Lake Michigan

Status: Mixed
Trend: Undetermined
Primary Factors Determining Status and Trend: Intermediate to high rate of land conversions to development. Of the 1.2 million ha watershed, 9,724 ha of wetland, 78,537 ha of agricultural land, and 57,529 ha of forest land were developed between 1992 and 2001.

Lake Huron

Status: Fair
Trend: Undetermined
Primary Factors Determining Status and Trend: Second lowest rate of conversion of land to development. Of the 4.1 million ha watershed area on the U.S. side, 4,314 ha of wetland, 17,881 ha of agricultural land, and 17,730 ha of forest land were developed between 1992 and 2001.

Lake Erie

Status: Poor
Trend: Undetermined
Primary Factors Determining Status and Trend: Highest conversion rate of non-developed to development LULC. Of the 5.0 million ha watershed area on the U.S. side, 3,352 ha of wetland, 52,502 ha of agricultural land, and 27,869 ha of forest land were developed between 1992 and 2001.

Lake Ontario

Status: Mixed
Trend: Undetermined

Primary Factors Determining Status and Trend	Intermediate to high conversion rate of non-developed to development LULC coupled with the lowest rates of wetland development. Of the 3.4 million ha watershed area on the U.S. side, 458 ha of wetland, 24,883 ha of agricultural land, and 20,670 ha of forest land were developed between 1992 and 2001.

Purpose

•To document the proportion of land in the Great Lakes basin under major land use classes, and assess the changes in land use over time; and

•To infer the potential impact of existing land cover and land conversion patterns on basin ecosystem health.

Ecosystem Objective

Sustainable development is a generally accepted land use goal. This indicator supports Annex 13 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Binational land use data from the early 1990s was developed by Guindon (Natural Resources Canada). Imagery data from the North American Landscape Characterization and the Canada Centre for Remote Sensing archive were combined and processed into land cover using Composite Land Processing System software. This data set divides the basin into four major land use classes – water, forest, urban, and agriculture and grasses.

Later, finer-resolution satellite imagery allowed analysis to be conducted in greater detail, with a larger number of land use categories. For instance, the Ontario Ministry of Natural Resources has compiled Landsat TM (Thematic Mapper) data, classifying the Canadian Great Lakes basin into 28 land use classes.

On the U.S. side of the basin, the Natural Resources Research Institute (NRRI) of the University of Minnesota – Duluth has developed a 25-category classification scheme (Table 1) based on 1992 National Land Cover Data (NLCD) from the U.S. Geological Survey supplemented by 1992 WISCLAND, 1992 GAP, 1996 C-CAP and raw Landsat TM data to increase resolution in wetland classes (Wolter et al. 2006). The 1992 Topologically Integrated Geographic Encoding and Reference (TIGER) data were also used to add roads on to the map. Within the U.S. basin, the NRRI found the following:

Between two nominal time periods (1992 and 2001), the U.S. portion of the Great Lakes watershed has undergone substantial change in many key LULC categories (Fig. 1). Of the total change that occurred (798,755 ha, 2.5 % of watershed area), salient transition categories included a 33.5 % increase in area of low-intensity development, a 7.5% increase in road area, and a decrease of forest area by over 2.3 % – the largest LULC category and area of change within the watershed. More than half of the forest losses involved transitions into **early successional vegetation** (ESV), and hence, will likely remain in forest production of some sort. However, nearly as much forest area was, for all practical purposes, permanently converted to developed land. Likewise, agriculture lost over 50,000 more hectares of land to development than forestland, much of which involved transitions into urban/suburban sprawl (See: Fig. 2).

Approximately 210,068 ha (81 %) of agricultural lands were converted to development, and 16.3 % of that occurred within 10 km of the Great Lakes shoreline.

Land use/land cover transitions between 1992 and 2001 within near-shore zones of the Great Lakes (0-1, 1-5, 5-10 km) largely parallel those of the overall watershed. While the same transition categories dominated, their proportions varied by buffered distance from the lakes. Within the 0-1 km zone from the Great Lakes shoreline, conversions of forest to both ESV (9,087 ha, 5.0 % of **total category change** (TCC)) and developed land (8,657 ha, 5.6 % of TCC) were the largest transitions, followed by conversion of 3,935 ha (1.9 % of TCC) of agricultural land to developed. For the 1-5 km zone inland from the shore, forest to developed conversion was the largest of the three transitions (17,049 ha, 11.0 % of TCC), followed by agricultural to developed (14,279 ha, 6.8 % of TCC) and forest to ESV (13,116 ha, 7.3 % of TCC). Within the 5-10 km zone from shoreline, transition category dominance was most similar to the trend for the whole watershed, with 16,113 ha (7.7 % of TCC) of agriculture converted to developed, 14,516 ha (8.0 % of TCC) of forest converted to ESV, and 14,390 ha (9.3 % of TCC) of forestland being developed by 2001. When all buffers form shoreline out to 10 km are combined, the forest to developed transition category was the largest (40,099 ha, 25.9 % of TCC), followed by forest to ESV (36,726 ha, 20.3 % of TCC), and agricultural to developed (34,328 ha, 16.3 % of TCC).

Contrary to previous decadal estimates showing an increasing forest area trend from the early 1980s to the early 1990s, due to agricultural abandonment and transitions of forest land away from active management, we observed an overall decrease (~2.3 %) in forest area between 1992 and 2001. Explanation of this trend is largely unclear; however, both increased forest harvesting practices in parts of the region coupled with forest clearing for new developments may be overshadowing gains from the agricultural sources observed in previous decades.

When analyzed on a lake-by-lake basis (Fig. 3, Table 2), Michigan's watershed naturally has experienced the greatest area of change from 1992 to 2001 (286587 ha, ~2.5 %), as its watershed is entirely within the U.S., and hence, the largest analyzed. Michigan's watershed leads in all LULC transition categories but two: 1) misc. veg. to flooded and 2) ESV to forest (Fig. 3). When normalized by area, however, Michigan's proportion of LULC change is intermediate when compared to the other Great Lakes watersheds on the U.S. side of the boarder. Although not a Great Lake, and largely metropolitan (See: Fig 2), Lake St. Clair's watershed shows the highest rates of change into development from wetland, ESV, agriculture, and forest sources (Fig. 4).

Of the Great Lakes, Erie's watershed shows the greatest proportion of land conversion to development (87,077 ha, 1.74 %), while Superior's watershed had the lowest proportion (20,351, 0.48 %) (Table 2). For example, Erie had the highest proportion of agricultural land conversion to development. However, Ontario's watershed showed the greatest proportion of forest conversion to development (Fig. 4). Superior's watershed reflects a high proportion of lands under forest management in that it has both the highest proportion of forest conversion to ESV and visa-versa. Lastly, Huron's watershed had the highest proportion of wetlands being converted to development, followed closely by Michigan and Erie (Fig. 4).

Management Implications
As the volume of data on land use and land conversion grows, stakeholder discussions will assist in identifying the associated pressures and management implications.

Comments from the author(s)
Land classification data must be standardized. The resolution should be fine enough to be useful at lake watershed and sub-watershed levels. LULC classification updates need to be completed in a timely manner to facilitate effective remedial action if necessary.

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Data Sources
Data courtesy of: Bert Guindon (Natural Resources Canada), Lawrence Watkins (Ontario Ministry of Natural Resources) and Peter Wolter (Natural Resources Research Institute at the University of Minnesota – Duluth). Forest Inventory and Analysis statewide data sets downloaded from USDA Forest Service website and processed by the author to extract data relevant to Great Lakes basin.

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Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006. Land use land cover change in the U.S. Great Lakes basin 1992 to 2001. J. Great Lakes Res. 32: 607-628.

Figure 4. Lake-by-lake LULC transitions for the U.S. portion of the Great Lakes basin as a percent of respective watershed area.
Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006. Land use land cover change in the U.S. Great Lakes basin 1992 to 2001. J. Great Lakes Res. 32: 607-628.

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(1)	Low Intensity Residential	1	Developed
(1)	High Intensity Residential	2	Agriculture
(1)	Commercial/Industrial	3	Early Successional Vegetation
(1)	Roads (Tiger 1992)	4	Forest
(3)	Bare Rock/Sand/Clay	5	Wetland
(1)	Quarries/Strip Mines/Gravel Pits	6	Miscellaneous Vegetation
(6)	Urban/Recreational Grasses		
(2)	Pasture/Hay		
(2)	Row Crops		
(2)	Small Grains		
(3,6)	Grasslands/Herbaceous		
(2,6)	Orchards/Vineyards/Other		
(4)	Deciduous Forest		
(4)	Evergreen Forest		
(4)	Mixed Forest		
(3,6)	Transitional		
(3,6)	Shrubland		
(5)	Open Water		
(5)	Unconsolidated Shore		
(5)	Emergent Herbaceous Wetlands		
(5)	Lowland Grasses		
(5)	Lowland Scrub/Shrub		
(5)	Lowland Conifers		
(5)	Lowland Mixed Forest		
(5)	Lowland Hardwoods		

Table 1. Classification scheme used to analyze LULC change in the U.S. portion of the Great Lakes basin. Original 25 classes are listed in the left column, while aggregated LULC categories are listed in the right column. Numbers in parentheses indicate aggregated class membership. Miscellaneous vegetation class was generated (code 6) to represent land that was vegetated, but not mature forest or annual row crop.
Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006

	Erie	Huron	Michigan	Ontario	Superior	St. Clair	Erie/St. Clair
Total watershed area	4994413	4114697	11702442	3428229	4226924	564825	5559238
Non-dev. to developed	87077	42857	155936	46507	20351	16112	103189
% of watershed	1.74	1.04	1.33	1.36	0.48	2.85	1.86

Table 2. Total area (ha) and proportion of watershed converted from non-developed to developed LULC from 1992 to 2001 for each of the Great Lakes and Lake St. Clair.
Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006

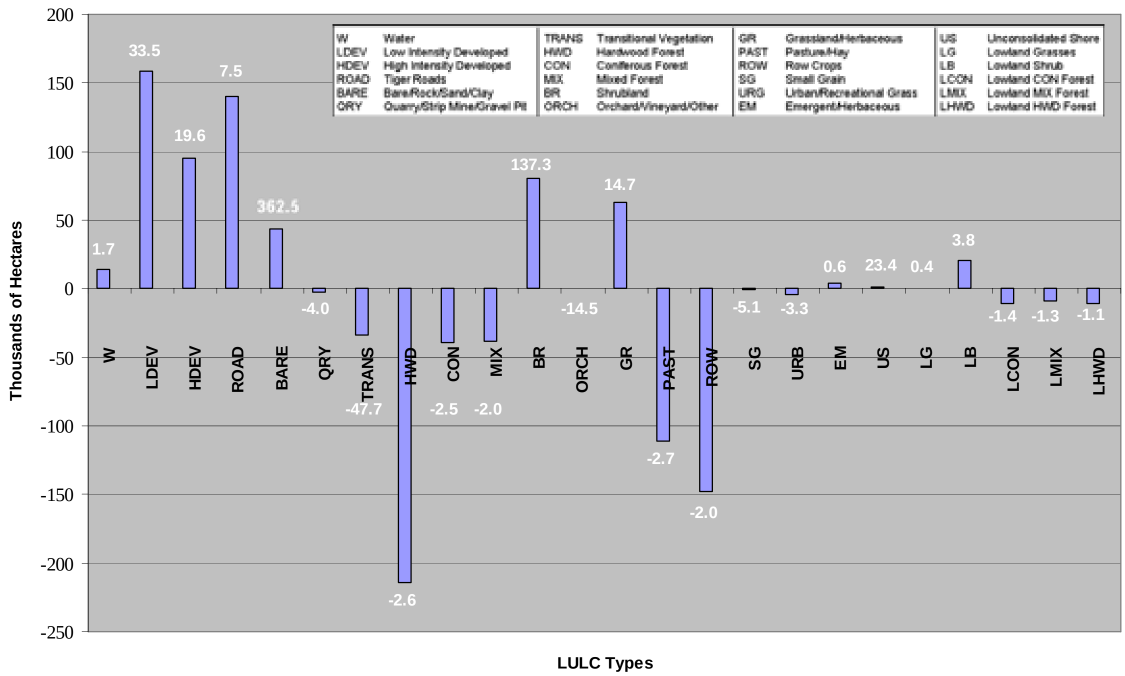

Figure 1. LULC type changes for the U.S. Great Lake basin by area and percent change since 1992 (numbers above and below bars).
Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006

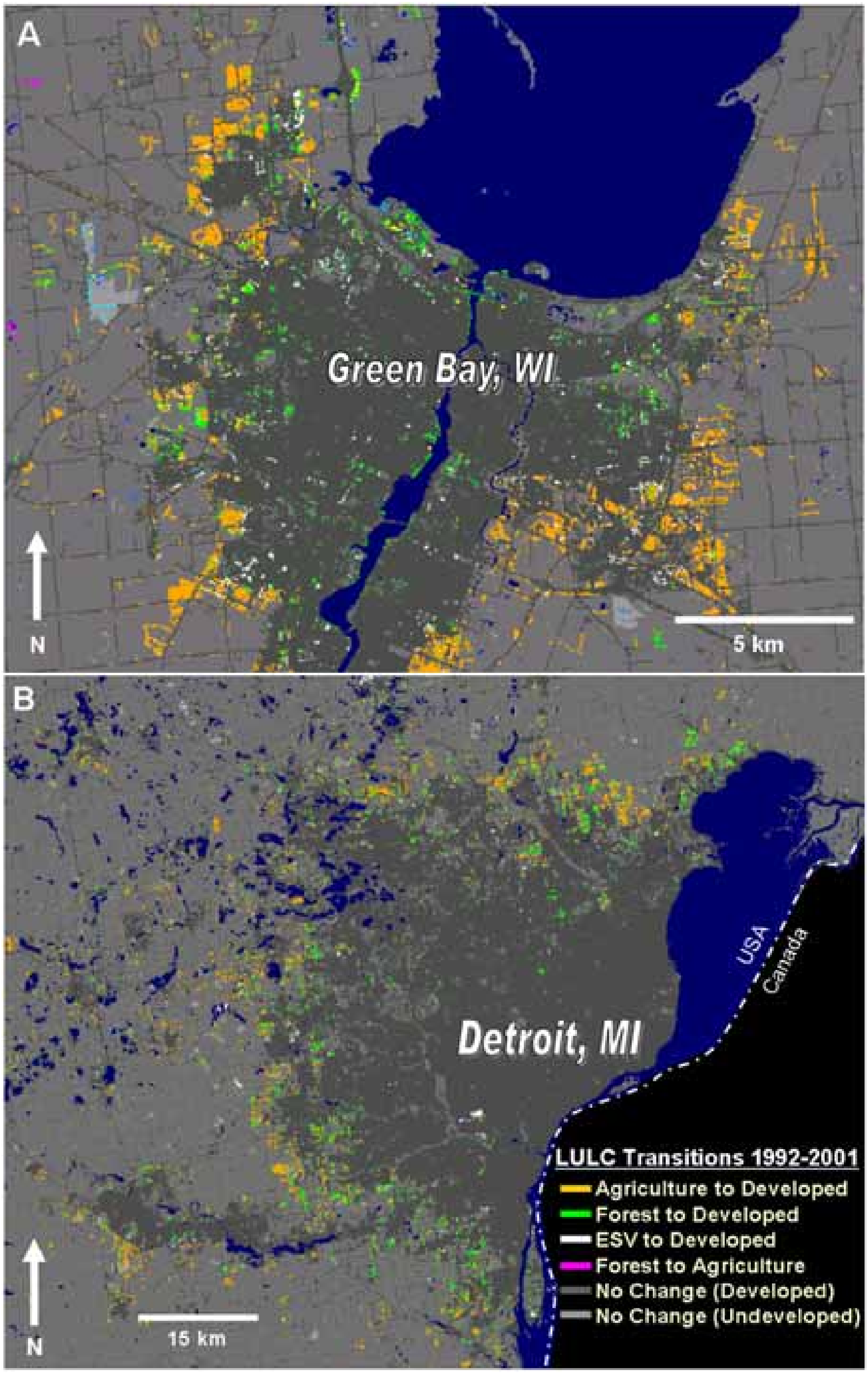

Figure 2. LULC change in the lower Green Bay basin of Lake Michigan (A) and the area surrounding Detroit, MI (B).
Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006

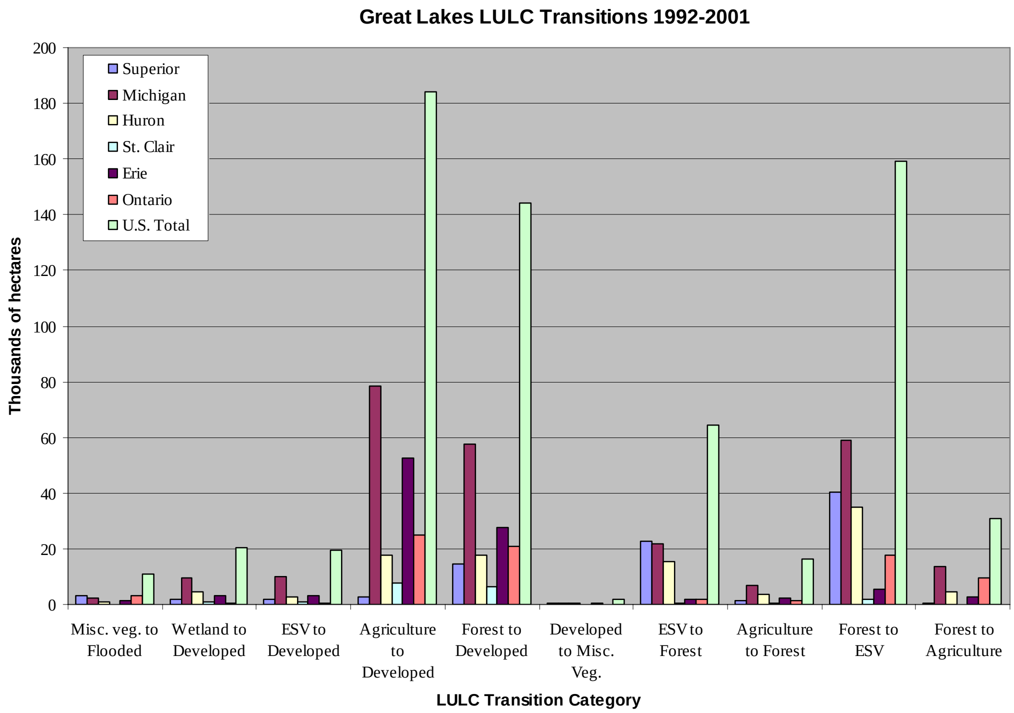

Figure 3. Lake-by-lake LULC transitions for the U.S. portion of the Great Lakes basin. Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006

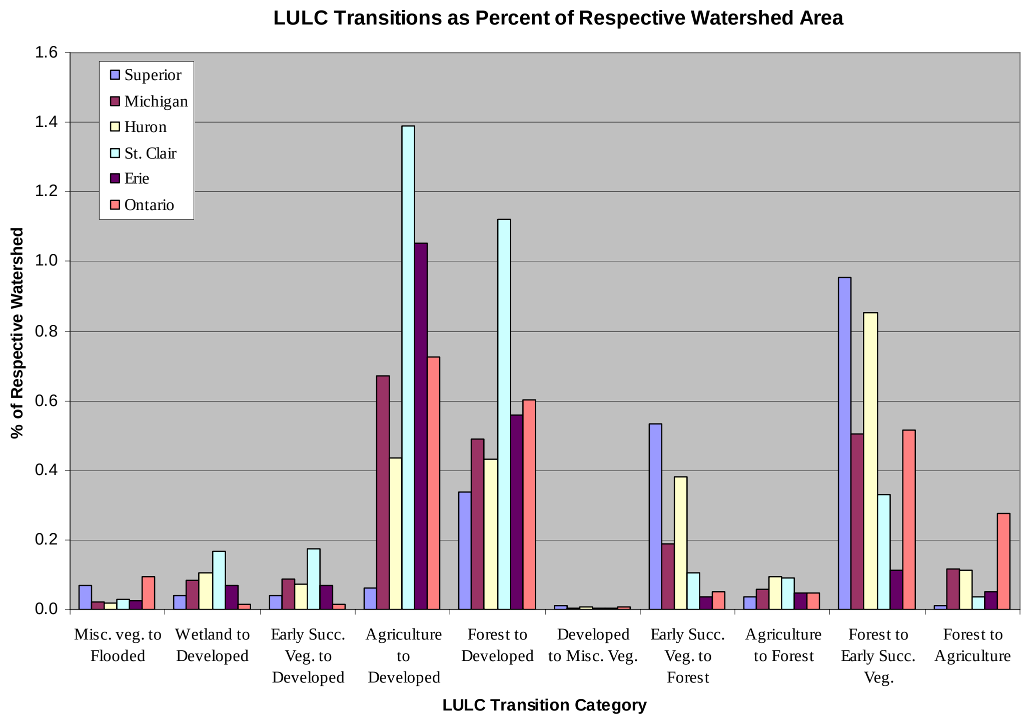

Figure 4. Lake-by-lake LULC transitions for the U.S. portion of the Great Lakes basin as a percent of respective watershed area.
Source: Wolter, P.T., Johnston, C.A., and Neimi, G.J. 2006

Brownfields Redevelopment

Indicator #7006

Overall Assessment

Status:	**Mixed**
Trend:	**Improving**
Primary Factors Determining Status and Trend	Data from multiple sources are not consistent. Inventories of existing brownfields are not available in Ontario so it is difficult to determine a trend for the redevelopment of brownfields. Since more sites are being redeveloped and/or are being planned, there is some trend of an improvement in the Great Lakes basin, but it is not based on a quantitative assessment. Funding and liability issues are obstacles for brownfields redevelopment and can hinder progress.

Purpose

- To assess the area of redeveloped brownfields; and
- To evaluate over time the rate at which society remediates and reuses former developed sites that have been degraded or abandoned.

Ecosystem Objective

The goal of brownfields redevelopment is to remove threats of contamination associated with these properties and to bring them back into productive use. Remediation and redevelopment of brownfields results in two types of ecosystem improvements:

1. reduction or elimination of environmental risks from contamination associated with these properties; and

2. reduction in pressure for open space conversion as previously developed properties are reused.

State of the Ecosystem

Brownfields are abandoned, idled, or under-used industrial and commercial facilities where expansion, redevelopment or reuse is complicated by real or perceived environmental contamination. In 1999, 21,178 brownfields sites were identified in the United States which was equivalent to approximately 33,010 hectares (81,568 acres) of land (The United States Conference of Mayors). Although similar research does not exist for Canada and no inventory exists for either contaminated or brownfields sites in Ontario, it is estimated that approximately 50,000 to 100,000 brownfields sites may exist in Canada (Globe 2006).

All eight Great Lakes states, Ontario and Quebec have programs to promote remediation or clean-up and redevelopment of brownfields sites. Several of the brownfields clean-up programs have been in place since the mid-to-late 1980s, but establishment of more comprehensive brownfields programs that focus on remediation and redevelopment has occurred during the 1990s. Today, each of the Great Lakes states has a voluntary clean-up or environmental response program and there are over 5,000 municipalities with some type of brownfields program in the U.S. (Globe 2006). These clean-up programs offer a range of risk-based, site-specific background and health clean-up standards that are applied based on the specifics of the contaminated property and its intended reuse.

In Quebec, the *Revi-Sols* program was established in 1998 and is aimed at assessing and cleaning urban contaminated sites for the purpose of reuse. Through this program, it was possible to collect some data on the number of contaminated sites in Quebec as it was compulsory for the land owner to report this information to complete the application for financing. Based on this program, more than 7,000 sites are included in this inventory.

To encourage redevelopment, Ontario's environmental legislation provides general protection from environmental orders for historic contamination to municipalities, creditors and others. Ontario Regulation 153/04, which came into effect on October 1, 2004, details the requirements that property owners must meet in order to file a record of site condition. Two technical documents are referenced by this regulation, one providing applicable site condition standards, the other providing laboratory analytical protocols for the analysis of soil, sediment and ground water. A Brownfields Environmental Site Registry offers property owners the opportunity to complete an online record of site condition with this information then being publicly accessible. This registry is currently voluntary. As of October 2005, property owners are required to file a record of site condition before a property or commercial use to a more sensitive area, such as residential. A record of site condition ensures that a property meets regulated site-assessment and clean-up standards that are appropriate for the new use (Ontario Legislation Promotes Stronger Healthier Community).

The 2003 enactment of the New York State Brownfield Law has resulted in increased interest by private developers and municipalities in the redevelopment of contaminated properties.

Efforts to track brownfields redevelopment are uneven among Great Lakes states and provinces. Not all jurisdictions track brownfields activities and methods vary where tracking does take place. States, provinces and municipalities track the amount of funding assistance provided as well as the number of sites that have been redeveloped. They also track the number of applications that have been received for brownfields redevelopment funding. These are indicators of the level of brownfields redevelopment activity in general, but they do not necessarily reflect land renewal efforts (i.e., area of land redeveloped), the desired measure for this indicator. Compiling state and provincial data to report a brownfields figure that represents the collective eight states and two provinces is challenging. Several issues are prominent. First, state and provincial clean-up data reflect different types of clean-ups, not all of which are "brownfields" (e.g. some include leaking underground storage tanks and others do not). Second, some jurisdictions have more than one program, and not necessarily all relevant programs engage in such tracking. Third, program figures do not include clean-ups that have not been part of a state or provincial clean-up program (e.g. local or private clean-ups). That said, several states and provinces do track acres of brownfields remediated, although no Great Lakes state or province tracks acres of brownfields redeveloped.

Information on area of brownfields remediated from Illinois, Minnesota, New York, Ohio, Pennsylvania, Quebec and Ontario indicate that, as of August, 2002, a total of 13,413 hectares (33,143 acres) have been remediated. Available data from eight Great Lakes states, Quebec and Ontario indicate that almost 27,000 brownfields sites have participated in brownfields clean-up programs since the mid-1990s, although the degree of remediation varies considerably. In

Ontario, brownfields redevelopment is planned for 108 hectares (267 acres) of land between 2006 and 2008 for the municipalities that participated in this assessment.

Remediation is a necessary precursor to redevelopment. Remediation is often used interchangeably with "clean-up," though brownfields remediation does not always involve removing or treating contaminants. Many remediation strategies utilize either engineering or institutional controls (also known as exposure controls) or adaptive reuse techniques that are designed to limit the spread of, or human exposure to, contaminants left in place. In many cases, the cost of treatment or removal of contaminants would prohibit reuse of land. All Great Lakes states and provinces allow some contaminants to remain on site as long as the risks of being exposed to those contaminants are eliminated or reduced to acceptable levels. Capping a site with clean soil or restricting the use of groundwater are examples of these "exposure controls" and their use has been a major factor in advancing brownfields redevelopment. Several jurisdictions keep track of the number and location of sites with exposure controls, but monitoring the effectiveness of such controls occurs in only three out of the ten jurisdictions.

Redevelopment is a criterion for eligibility under many state brownfields clean-up programs. Though there is inconsistent and inadequate data on area of brownfields remediated and/or redeveloped, available data indicate that both brownfields clean-up and redevelopment efforts have risen dramatically in the mid-1990s and steadily since 2000. The increase is due to risk-based clean-up standards and the widespread use of state liability relief mechanisms that allow private parties to redevelop, buy or sell properties without being liable for contamination they did not cause. Canadian law does not provide liability exemptions for new owners such as those in the U.S. Small Business Liability Relief and Brownfields Revitalization Act (Globe 2006). Environmental liability is a major barrier to successful brownfields redevelopment in Canada. Current owners do not want to sell brownfields sites for fear of liability issues in the future, purchasers of land do not want to buy sites without some level of protection and municipalities assume liability when they become site owners (Brownfields Redevelopment versus Greenfield Development). The Ontario Ministry of Finance has proposed changes under Bill 130 (Municipal Statute Law Amendment Act, 2006) which would allow brownfields to be advertised as "free" of any provincial crown liens if a municipality assumes ownership of a property with a failed tax sale. Also, under certain circumstances, this new policy will allow for the removal of crown liens on brownfields properties at tax sale. If passed, this change in legislation would reduce some of the issues related to civil and regulatory liabilities. One recommendation is that once a property owner has met regulatory standards in the cleanup phase that they are not forced to meet stricter standards in the future.

In 2005, the Government of Canada allocated $150 million for brownfields remediation. Other initiatives include the Sustainable Technologies Canada Funding, and the Federal Contaminated Sites Action Plan. Also, more financial tools for brownfields redevelopment are available though a Community Improvement Plan (CIP), which allows municipalities to encourage brownfields redevelopment by offering financial incentives. Other grants and loans can be provided to supplement the CIP including an exemption or a reduction in the cost of fees associated with permits, parkland dedications and zoning amendments. Tax incentives can also be provided by municipalities to encourage the cleanup of contaminated sites (Financial Tools for Brownfields Redevelopment).

Data also indicate that the majority of clean-ups in the Great Lakes states and provinces are occurring in older urbanized areas, many of which are located on the shoreline of the Great Lakes and in the basin. Based on the available information, the state of brownfields redevelopment is **mixed** and **improving**.

Pressures

Laws and policies that encourage new development to occur on undeveloped land instead of on urban brownfields, are significant and on-going pressures that can be expected to continue. Programs to monitor, verify and enforce effectiveness of exposure controls are in their infancy, and the potential for human exposure to contaminants may inhibit the redevelopment of brownfields. Several Great Lakes states allow brownfields redevelopment to proceed without cleaning up contaminated groundwater as long as no one is going to use or come into contact with that water. However, where migrating groundwater plumes ultimately interface with surface waters, some surface water quality may continue to be at risk from brownfields contamination even where brownfields have been remediated.

Management Implications

Programs to monitor and enforce exposure controls need to be fully developed and implemented. More research is needed to determine the relationship between groundwater supplies and Great Lakes surface waters and their tributaries. Because brownfields redevelopment results in both reduction or elimination of environmental risks from past contamination and reduction in pressure for open space land conversion, data should be collected that will enable an evaluation of each of these activities. For every hectare (2.5 acres) developed in a brownfields project, it can save an estimated minimum of 4.5 hectares (11 acres) of land from being developed in an outlying area (Cleaning Up the Past, Building the Future).

Ontario is expected to add 3.7 million more people to its population in the next 25 years with most of the growth occurring in the Greater Golden Horseshoe (western end of Lake Ontario) (Places to Grow: Better Choices, Brighter Future). Brownfields redevelopment needs to be a part of the planning and development reform in order to address the issue of urban sprawl.

Comments from the author(s)

Great Lakes states and provinces have begun to track brownfields remediation and or redevelopment, but the data is generally inconsistent or not available in ways that are helpful to assess progress toward meeting the terms of the Great Lakes Water Quality Agreement. Though some jurisdictions have begun to implement web-based searchable applications for users to query the status of brownfields sites, the data gathered are not necessary consistent, which presents challenges for assessing progress in the entire basin. States and provinces should develop common tracking methods and work with local jurisdictions incorporating local data to online databases that can be searched by: 1) area remediated; 2) mass of contamination removed or treated (i.e., not requiring an exposure control); 3) type of treatment; 4) geographic location; 5) level of urbanization; and 6) type of reuse (i.e., commercial, residential, open, none, etc). A recent development in the province of Ontario is the designation of a Provincial Brownfields Coordinator who will coordinate provincial brownfields activities and provide a single point of access on brownfields in Ontario.

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City of Toronto Economic Development Corporation (TEDCO)
Province of Quebec, Michel Beaulieu

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List of Tables

Source: Various state, municipal and provincial brownfields coordinators and city planners

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State/Province	Acres remediated	Hectares remediated	Time frame	Sites remediated	Time frame
WI	1,220	494	2004-2006	18,000	1994-2005
PA	13,229	5354	2000- 2006	1,097	1996-2002
OH	4,204	1701	1994-2006	156	1996-2002
MI	not tracked	not tracked		5,539†	1995-2002
IN	not tracked	not tracked		382	1997-2002
MN	7,047	2852	1998-2002	462	1998-2002
IL	6,412	2595	1990-2001	899	1990-2001
NY	55	22	2000-2002	16	2000-2002
ON	92	37	2002-2005	13	2002-2005
QC	741	300	1998-2002	309	1998-2005
Total	**33,143**	**13,413**		**26,873**	

Table 1. Summary of acres remediated and number of sites remediated in the Great Lakes basin, 1990 – 2006.
Source: Various state, municipal and provincial brownfields coordinators and city planners

Figure 1. Redeveloped brownfields site, Spencer Creek, Hamilton, Ontario.
Source: City of Hamilton

Sustainable Agriculture Practices

Indicator #7028

Assessment: Not Assessed

Purpose

- To assess the number of environmental and conservation farm plans and environmentally friendly practices in place such as: integrated pest management to reduce the potential adverse impacts of pesticides; conservation tillage and other soil preservation practices to reduce energy consumption and sustain natural resources and to prevent ground and surface water contamination.

Ecosystem Objective

The goal is to create a healthy and productive land base that sustains food and fiber, maintains functioning watersheds and natural systems, enhances the environment and improves the rural landscape. The sound use and management of soil, water, air, plant, and animal resources is needed to prevent degradation of agricultural resources. The process integrates natural resource, economic, and social considerations to meet private and public needs. This indicator supports Annex 2, 3, 12 and 13 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Background

Agriculture accounts for approximately 35% of the land area of the Great Lakes basin and dominates the southern portion of the basin. In years past, excessive tillage and intensive crop rotations led to soil erosion and the resulting sedimentation of major tributaries. Inadequate land management practices contributed to approximately 57 metric tons of soil eroded annually by the 1980s. Ontario estimated its costs of soil erosion and nutrient/pesticide losses at $68 million (CA) annually. In the United States, agriculture is a major user of pesticides, with an annual use of 24,000 metric tons. These practices lead to a decline of soil organic matter. Since the late 1980s, there has been increasing participation by Great Lakes basin farmers in various soil and water quality management programs. Today's conservation systems have reduced the rates of U.S. soil erosion by 38% in the last few decades. The adoption of more environmentally responsible practices has helped to replenish carbon in the soils back to 60% of turn-of-the-century levels.

Both the Ontario Ministry of Agriculture and Food (OMAF) and the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) provide conservation planning advice, technical assistance and incentives to farm clients and rural landowners. Clients develop and implement conservation plans to protect, conserve, and enhance natural resources that harmonize productivity, business objectives and the environment. Successful implementation of conservation planning depends largely upon the voluntary participation of clients. Figure 1 shows the number of acres of cropland in the U.S. portion of the Great Lakes basin that are covered under a conservation plan.

The Ontario Environmental Farm Plan (EFP) encourages farmers to develop action plans and adopt environmentally responsible management practices and technologies. Since 1993, the Ontario Farm Environmental Coalition (OFEC), OMAF, and the Ontario Soil and Crop Improvement Association (OSCIA) have cooperated to deliver EFP workshops. The Canadian federal government, through various programs over the years, has pro-

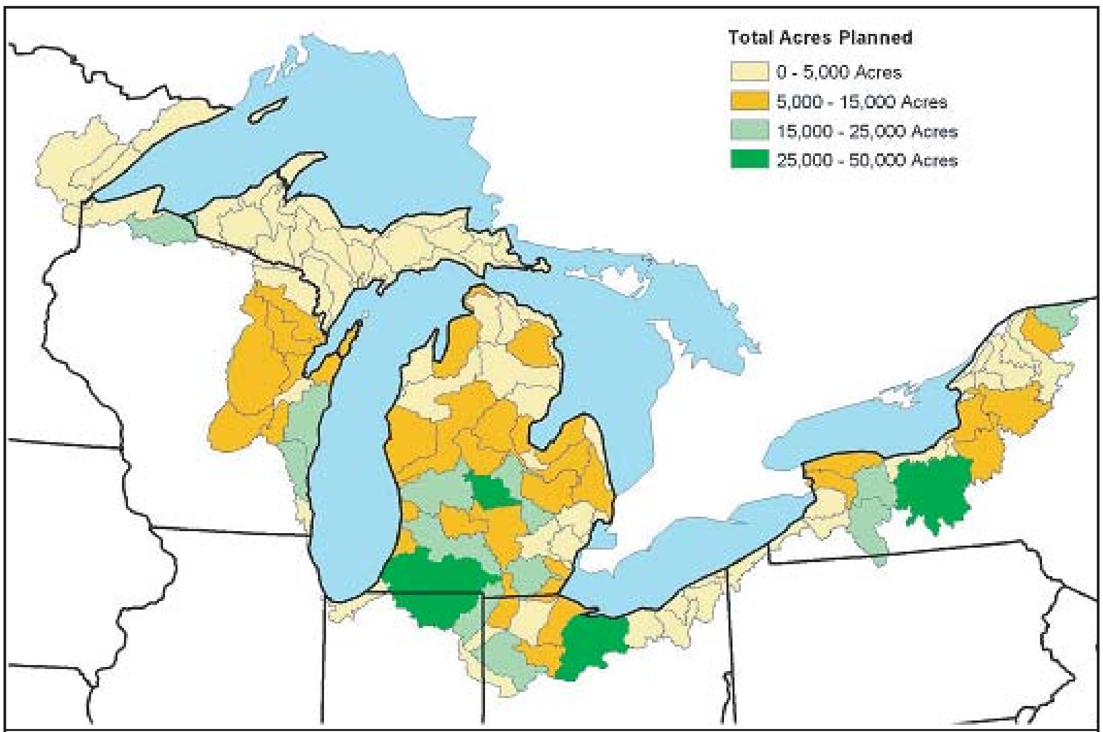

Figure 1. Acres of cropland in U.S portion of the basin covered under a conservation plan, 2003.
Source: Natural Resource Conservation Service, U.S. Department of Agriculture

vided funding for EFP. As can be seen from Figure 2 the number of EFP incentive claims rose dramatically from 1997 through 2004, particularly for the categories of soil management, water wells, and storage of agricultural wastes. As part of Ontario's Clean Water Strategy, the Nutrient Management Act (June 2002) is setting province-wide standards to address the effects of agricultural practices on the environment, particularly as they relate to land-applied materials containing nutrients.

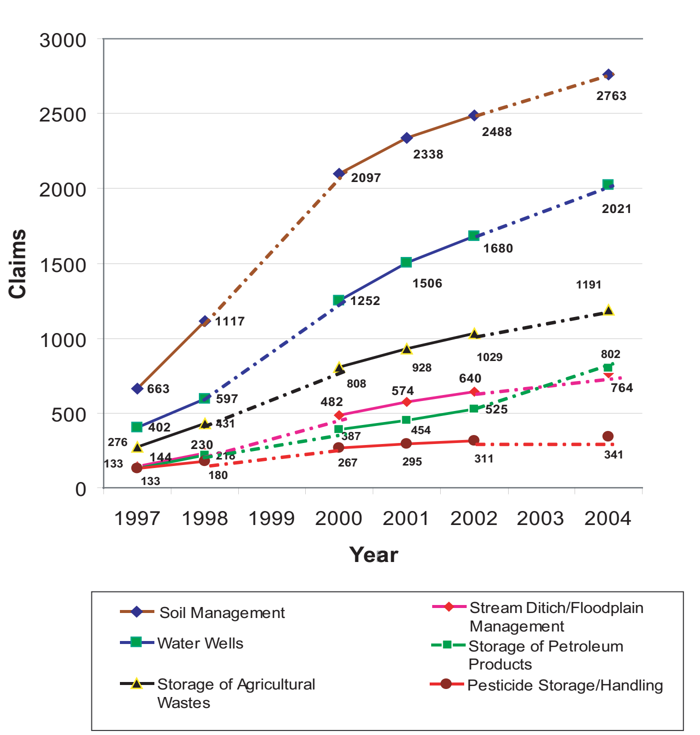

Figure 2. EFP: Cumulative Number of Incentive Claims by Worksheet (Issues). Six of 23 worksheets/issues are represented here - these six worksheets represent 70% of all EFP incentive claims. Three worksheets (Soil, Water and Storage of Agricultural Wastes) represent significant environmental actions taken by farmers.
Source: Ontario Soil and Crop Improvement Association

USDA's voluntary Environmental Quality Incentives Program provides technical, educational, and financial assistance to landowners that install conservation systems. The Conservation Reserve Program allows landowners to convert environmentally sensitive acreage to vegetative cover. States may add funds to target critical areas under the Conservation Reserve Enhancement Program. The Wetlands Reserve Program is a voluntary program to restore wetlands.

Pressures

The trend towards increasing farm size and concentration of livestock will change the face of agriculture in the basin. Development pressure from the urban areas may increase the conflict between rural and urban landowners. This can include pressures of higher taxes, traffic congestion, flooding, nuisance complaints (odours) and pollution. By urbanizing farmland, we may limit future options to deal with social, economic, food security and environmental problems.

Management Implications

In June of 2002, the Canadian government announced a multi-billion dollar Agricultural Policy Framework (APF). It is a national plan to strengthen Canada's agricultural sector, with a goal for Canada to be a world leader in food safety and quality, and in environmentally responsible production and innovation, while improving business risk management and fostering renewal. As part of the APF, the Canadian government is making a $100 million commitment over a 5-year period to help Canadian farmers increase implementation of EFPs. The estimated commitment to Ontario for the environment is $67.66 million while the province is committing $42.72 million. These funds are available to Ontario's farmers since the federal government has signed a contribution agreement with the OFEC in the spring of 2005. This is expected in the fall of 2004. Currently Ontario's Environmental Farm Plan workbook has been revised for new APF farm planning initiatives launched in the spring of 2005. Ontario Farm Plan workshops are being delivered starting in the spring of 2005 under the new APF initiative.

In the spring of 2004, OMAF released the Best Management Practices (BMP) book *Buffer Strips*. This book assists farmers to establish healthy riparian zones and address livestock grazing systems near water – two important areas for improvements in water quality and fish habitat. Pesticide use surveys, conducted every 5 years since 1983, were conducted in 2003. Results were released in June 2004.

The U.S. Clean Water Action Plan of 1998 calls for USDA and the U.S. Environmental Protection Agency (USEPA) to cooperate further on soil erosion control, wetland restoration, and reduction of pollution from farm animal operations. National goals are to install 2 million miles of buffers along riparian corridors by 2002 and increase wetlands by 100,000 acres annually by 2005. Under the 1999 USEPA/USDA Unified National Strategy for Animal Feeding Operation (AFO), all AFOs will have comprehensive nutrient management plans implemented by 2009. The Conservation Security Program was launched in 2004, and it provides financial incentives and rewards for producers who meet the highest standards of conservation and environmental management on their operations.

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Last Updated

State of the Great Lakes 2005

Economic Prosperity

Indicator #7043

Assessment: Mixed (for Lake Superior Basin), Trend Not Assessed
Data are not system-wide.

Purpose

- To assess the unemployment rates within the Great Lakes basin; and
- To infer the capacity for society in the Great Lakes region to make decisions that will benefit the Great Lakes ecosystem (when used in association with other Great Lakes indicators).

Ecosystem Objective

Human economic prosperity is a goal of all governments. Full employment (i.e. unemployment below 5% in western societies) is a goal for all economies.

State of the Ecosystem

This information is presented to supplement the report on Economic Prosperity in SOLEC 2000 Implementing Indicators (Draft for Review, November 2000). In 1975, 1980, 1985, 1990, 1995 and 2000 the civilian unemployment rate in the 16 U.S. Lake Superior basin counties averaged about 2.0 points above the U.S. average, and above the averages for their respective states, except occasionally Michigan (Figure 1). For example, the unemployment rate in the four Lake Superior basin counties in Minnesota was consistently higher than for Minnesota overall, 2.7 points on average but nearly double the Minnesota rate of 6.0% in 1985. Unemployment rates in individual counties ranged considerably, from 8.6% to 26.8% in 1985, for example.

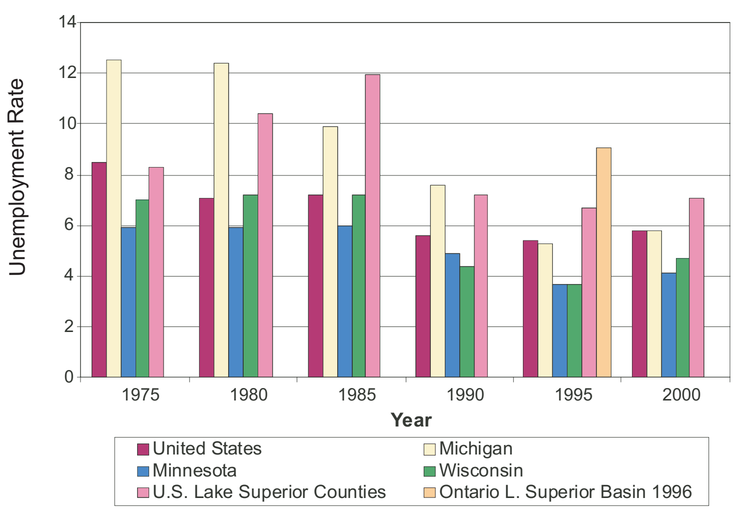

Figure 1. Unemployment rate in the U.S. (national), Michigan, Wisconsin, and the U.S. portion and Ontario portion of the Lake Superior basin, 1975-2000.
Source: U.S. Census Bureau and Statistics Canada

In the 29 Ontario census subdivisions mostly within the Lake Superior watershed, the 1996 unemployment rate for the population 15 years and over was 11.5%. For the population 25 years and older, the unemployment rate was 9.1%. By location the rates ranged from 0% to 100%; the extremes, which occur in adjacent First Nations communities, appear to be the result of small populations and the 20% census sample. The most populated areas, Sault Ste. Marie and Thunder Bay, had unemployment rates for persons 25 years and older of 9.4% and 8.6%, respectively. Of areas with population greater than 200 in the labour force, the range was from 2.3% in Terrace Bay Township to 31.0% in Beardmore Township. Clearly, the goal of full employment (less than 5% unemployment) was not met in either the Canadian or the U.S. portions of the Lake Superior basin during the years examined.

Acknowledgments
Authors: Kristine Bradof, GEM Center for Science and Environmental Outreach, Michigan Technological University, MI; and
James G. Cantrill, Communication and Performance Studies, Northern Michigan University, MI.

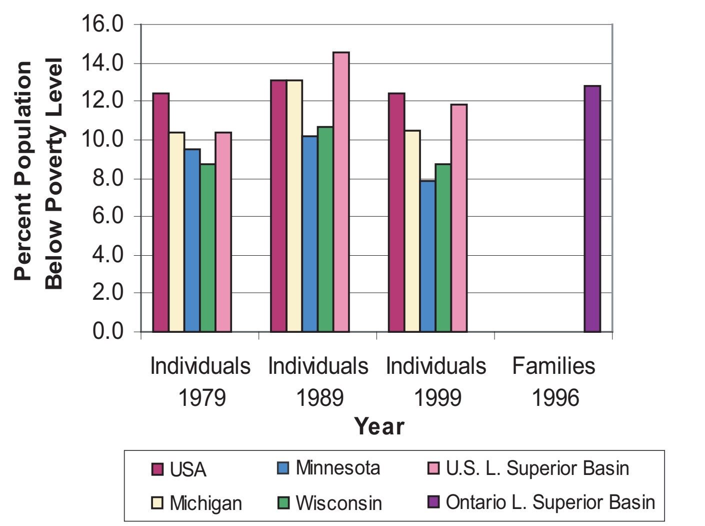

Figure 2. Individuals below poverty level in the U.S. (national), Michigan, Wisconsin, and the U.S. Great Lakes basin counties, 1979-1999, and families below poverty level in Ontario Great Lakes basin subdivisions, 1996.
Source: U.S. Census Bureau and Statistics Canada

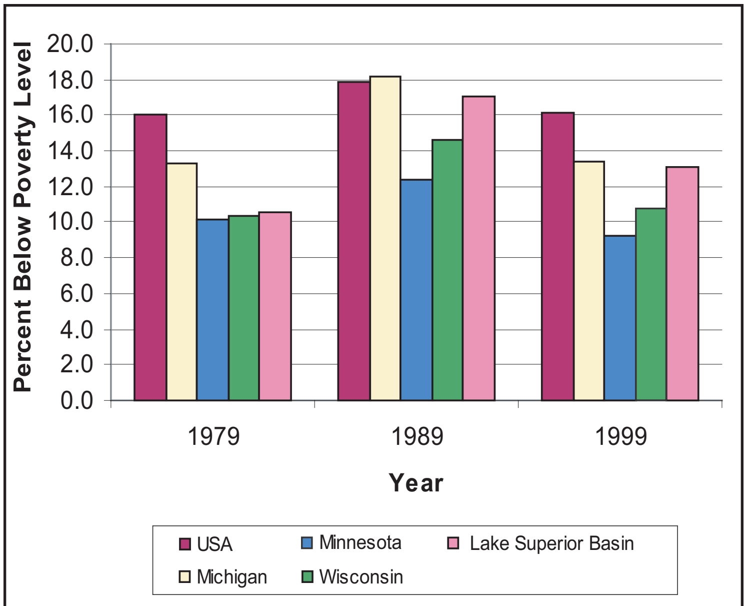

Figure 3. Children under age 18 below the poverty level, 1979-1999, U.S. (national), Michigan, Minnesota, Wisconsin and U.S. portion of the Lake Superior basin.
Source: U.S. Census Bureau

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Authors' Commentary

As noted in the State of the Great Lakes 2001 report for this indicator, unemployment may not be sufficient as a sole measure. Other information that is readily available from the U.S. Census Bureau and Statistics Canada includes poverty statistics for the overall population, children under age 18, families, and persons age 65 and older. Two examples of trends in those measures are shown in Figures 2 and 3. For persons of all ages within the U.S. Lake Superior basin for whom poverty status was established, 10.4% were below the poverty level in 1979. That figure had risen to 14.5% in 1989, a rate of increase higher than the states of Michigan, Minnesota, and Wisconsin and the U.S. overall over the same period. Poverty rates for individuals and children in the U.S. Lake Superior basin in 1979, 1989, and 1999 ranged from 10.4% to 17.1%, while 12.8% of families in the Ontario Lake Superior basin had incomes below the poverty level in 1996. Poverty rates in all areas were lower in 1999, but the U.S. Lake Superior basin (and Ontario portion of the basin in 1996) was higher than any of the three states. The 1979 poverty rate for counties within the Lake Superior basin ranged from a low of 4.4% in Lake County, Minnesota, to a high of 17.0% in Houghton County, Michigan. In 1989 and 1999, those same counties again were the extremes. Similarly, among children under age 18, poverty rates in the Great Lakes basin portions of the three states in 1979, 1989, and 1999 exceeded the rates of Minnesota and Wisconsin as a whole, though they remained below the U.S. rate. In a region where one-tenth to one-sixth of the population lives in poverty, environmental sustainability is likely to be perceived by many as less important than economic development.

Last Updated

State of the Great Lakes 2003

Water Withdrawals

Indicator #7056

Assessment: Mixed, Unchanging

Purpose

- To use the rate of water withdrawal to help evaluate the sustainability of human activity in the Great Lakes basin.

Ecosystem Objective

The first objective is to protect the basin's water resources from long-term depletion. Although the volume of the Great Lakes is vast, less than one percent of their waters are renewed annually through precipitation, run-off and infiltration. Most water withdrawn is returned to the watershed, but water can be lost due to evapotranspiration, incorporation into manufactured goods, or diversion to other drainage basins. In this sense, the waters of the Great Lakes can be considered a non-renewable resource.

The second objective is to minimize the ecological impacts stemming from water withdrawals. The act of withdrawing water can shift the flow regime, which in turn can affect the health of aquatic ecosystems. Water that is returned to the basin after human use can also introduce contaminants, thermal pollution or invasive species into the watershed. The process of withdrawing, treating and transporting water also requires energy.

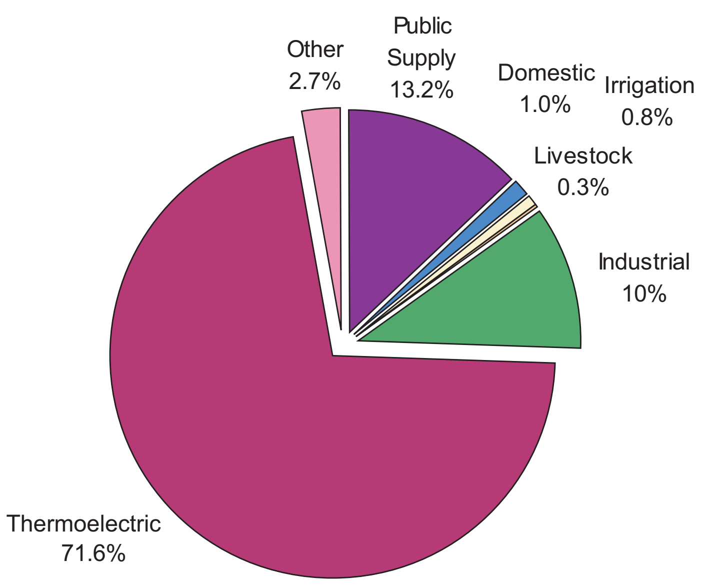

Figure 1. Water Withdrawals in the Great Lakes basin, by category as percentage of total, 2000.
Source: Great Lakes Commission, 2004

State of the Ecosystem

Water was withdrawn from the Great Lakes basin at a rate of 46,046 million gallons per day (MGD) in 2000 (or 174 billion litres per day), with almost two-thirds withdrawn in the U.S. side (30,977 MGD) and the remaining one-third in Canada (15,070 MGD). Self-supplying thermoelectric and industrial users withdrew over 80% of the total. Public water systems, which are the municipal systems that supply households, commercial users and other facilities, comprised 13% of withdrawals. The rural sector, which includes both domestic and agricultural users, withdrew 2%, with the remaining 3% used for environmental, recreation, navigation and quality control purposes. Hydroelectric use, which is considered "in-stream use" because water is not actually removed from its source, accounted for additional withdrawals at a rate of 799,987 MGD (Figure 1) (GLC 2004).

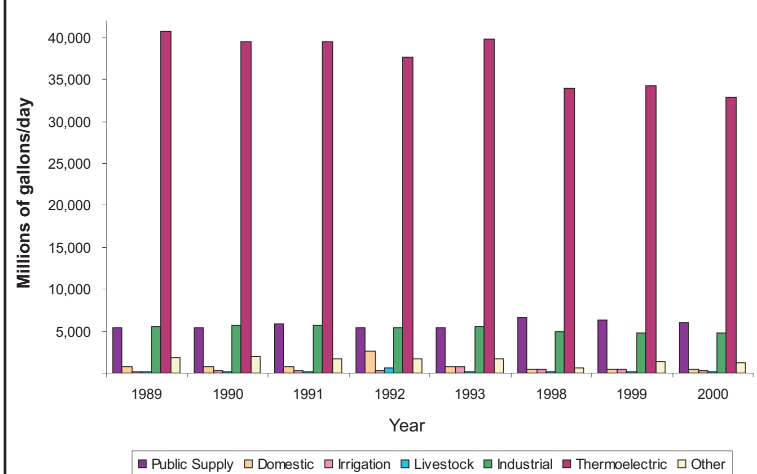

Figure 2. Great Lakes basin water withdrawals by category, 1989-1993 and 1998-2000.
Source: Great Lakes Commission, 1991-2004

Withdrawal rates in the late 1990s were below their historical peaks and do not appear to be increasing at present. On the U.S. side, withdrawals have dropped by more than 20% since 1980, following rapid increases from the 1950s onwards (USGS 1950-2000)[1]. Canadian withdrawals continued rising until the mid-1990s, but have decreased by roughly 30% since then (Harris and Tate 1999)[2]. In both countries, the recent declines have been caused by the shutdown of nuclear power facilities, advances in water efficiency in the industrial sector, and growing public awareness on resource conservation. Part of the decrease, however, may be attributed to improvements in data collection methods over time (USGS 1985). Refer to Figures 2,3 and 4.

The majority of waters withdrawn are returned to the basin through run-off and discharge. Approximately 5% is made unavailable, however, through evapotranspiration or

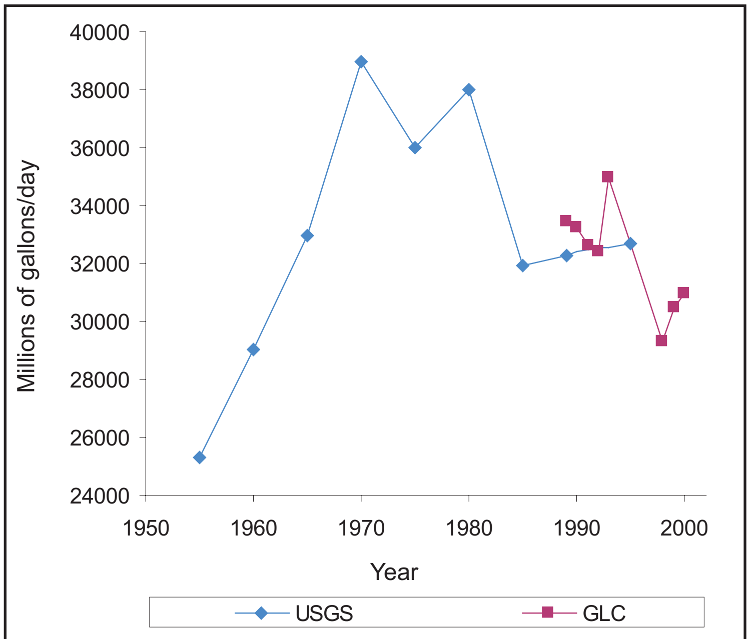

Figure 3. U.S. basin water withdrawals, 1950-2000. Source: U.S. Geological Survey, 1950-2000. Great Lakes Commission (GLC).

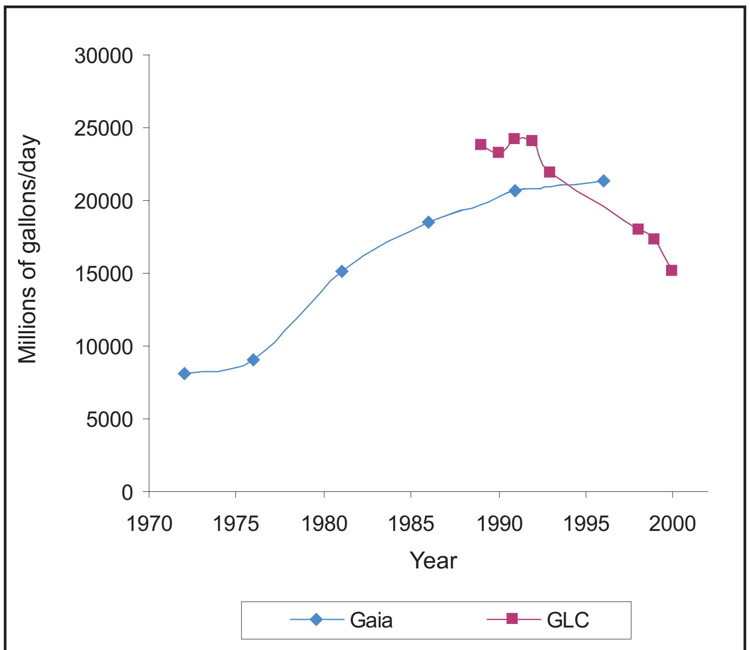

Figure 4. Canadian basin water withdrawals, 1972-2000. Source: Gaia Economic Research Associates, 1999 (based on data from Environment Canada and Statistics Canada). Great Lakes Commission (GLC).

incorporation into manufactured products. This quantity, referred to as "consumptive use," represents the volume of water that is depleted due to human activity. It is argued that consumptive use, rather than total water withdrawals, provides a more suitable indicator on the sustainability of human water use in the region. Basin-wide consumptive use was estimated at 3,166 MGD in 2000. Although there is no consensus on an optimal rate of consumptive use, a loss of this magnitude does not appear to be placing significant pressure on water resources. The long-term Net Basin Supply of water (sum of precipitation and run-off, minus natural evapotranspiration), which represents the maximum volume that can be consumed without permanently reducing the availability of water, and equals the volume of water discharged from Lake Ontario into the St. Lawrence River, is estimated to be 132,277 MGD (estimate is for 1990-1999 period, Environment Canada 2004). It should be noted, however, that focusing on these basin-wide figures can obscure pressures at the local watershed level.

Moreover, calculating consumptive use is a major challenge because of the difficulty in tracking the movement of water through the hydrologic cycle. Consumptive use is currently inferred by multiplying withdrawals against various coefficients, depending on use type. For instance, it is assumed that thermoelectric users consume as little as 1% of withdrawals, compared to a loss rate of 70-90% for irrigation (GLC 2003). There are inconsistencies in the coefficients used by the various states and provinces. Estimating techniques were even more rudimentary in the past, making it problematic to discuss historical consumptive use trends. Due to these data quality concerns, it may not yet be appropriate to consider consumptive use as a water use indicator.

Water removals from diversions, by contrast, are monitored more closely, a result of the political attention that prompted the region's governors and premiers to sign the Great Lakes Charter in 1985. The Charter and its Annexes require basin-wide notification and consultation for water exports, while advocating that new diversions be offset by a commensurate return of water to the basin. The two outbound diversions approved since 1985 have accommodated this goal by diverting water in from external basins. The outbound diversions already in operation by 1985, most notably the Chicago diversion, were not directly affected by the Charter, but these losses are more than offset by inbound diversions located in northwestern Ontario. Thus, there is currently no net loss of water due to diversions.

There is growing concern over the depletion of groundwater resources, which cannot be replenished following withdrawal with the same ease as surface water bodies. Groundwater was withdrawn at a rate of 1,541 MGD in 2000, making up 3% of total water withdrawals (GLC 2004). This rate may not have a major effect on the basin as a whole, but high-volume withdrawals have outstripped natural recharge rates in some locations. Rapid groundwater withdrawals in the Chicago-

Milwaukee region during the late 1970s produced cones of depression in that local aquifer (Visocky 1997). However, the difficulty in mapping the boundaries of groundwater supplies makes unclear whether the current groundwater withdrawal rate is sustainable.

Pressures

The Great Lakes Charter, and its domestic legal corollaries in the U.S. and Canada, was instituted in response to concerns over large-scale water exports to markets such as the arid southwestern U.S. There does not appear to be significant momentum for such long distance shipments due to legal and regulatory barriers, as well as technical difficulties and prohibitive costs. In the immediate future, the greatest pressure will come from communities bordering the basin, where existing water supplies are scarce or of poor quality. These localities might look to the Great Lakes as a source of water. Two border-basin diversions have been approved under the Charter and have not resulted in net losses of water to the basin. This outcome, however, was achieved through negotiation and was not proscribed by treaty or law.

As for withdrawals within the basin, there is no clear trend in forecasting regional water use. Reducing withdrawals, or at least mitigating further increases, will be the key to lessening consumptive use. Public water systems currently account for the bulk of consumptive use, comprising one-third of the total, and withdrawals in this category have been increasing in recent years despite the decline in total withdrawals. Higher water prices have been widely advocated in order to reduce water demand. Observers have noted that European per-capita water use is only half the North American level, while prices in the former are twice as high. However, economists have found that both residential and industrial water demand in the U.S. and Canada are relatively insensitive to price changes (Renzetti 1999, Burke *et al.* 2001)[3]. The over-consumption of water in North America may be more a product of lifestyle and lax attitudes. Higher prices may still be crucial for providing public water systems with capital for repairs; this can prevent water losses by fixing system leaks, for example. But reducing the underlying demand may require other strategies in addition to price increases, such as public education on resource conservation and promotion of water-saving technologies.

Assessing the availability of water in the basin will be complicated by factors outside local or human control. Variations in climate and precipitation have produced long-term fluctuations in surface water levels in the past. Global climate change could cause similar impacts; research suggests that water levels may be permanently lower in the future as a result. Differential movement of the Earth's crust, a phenomenon known as isostatic rebound, may exacerbate these effects at a local level. The crust is rising at a faster rate in the northern and eastern portions of the basin, shifting water to the south and west. These crustal movements will not change the total volume of water in the basin, but may affect the availability of water in certain areas.

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Endnotes

1 USGS estimates show water withdrawals in the U.S. Great Lakes watershed increasing from 25,279 MGD in 1955 to a peak in the 36-39,000 MGD range during the 1970-80 period, but dropping to the 31-32,000 MGD range for 1985-1995. GLC reported U.S. water withdrawals in the 32-34,000 range for 1989-1993, and around 30,000 MGD since 1998, with 30,977 MGD in 2000.

2 Historical Canadian data from Gaia Economic Research Associates (GERA) report, and are based on data from Statistics Canada and Environment Canada. GERA reported that Canadian water withdrawals increased from 8,136 MGD in 1972 to 21,316 MGD in 1996. GLC reported Canadian withdrawals of 21-24,000 MGD in 1989-1993, around 17,000 MGD for 1998 and 1999, and 15,070 MGD in 2000.

3 Econometric studies of both residential and industrial water demand consistently display relatively small price elasticities. Literature review on water pricing economics can be found in Renzetti (1999). However, the relationship between water demand and price structure is complex. The introduction of volumetric pricing (metering), as opposed to flat block pricing (unlimited use), is indeed associated with lower water use, perhaps because households become more aware of their water withdrawal rate (Burke *et al.* 2001).

Authors' Commentary
Water withdrawal data is already being compiled on a systemic basis. However, improvements can be made in collecting more accurate numbers. Reporting agencies in many jurisdictions do not have, or do not exercise, the statutory authority to collect data directly from water users, relying instead on voluntary reporting, estimates, and models. Progress is also necessary in establishing uniform and defensible measures of consumptive use, which is the component of water withdrawals that most clearly signals the sustainability of current water demand.

Mapping the point sources of water withdrawals could help identify local watersheds that may be facing significant pressures. In many jurisdictions, water permit or registration programs can provide suitable geographic data. However, only in a few states (Minnesota, Illinois, Indiana and Ohio) are withdrawal data available per registered facility. Permit or registration data, moreover, has limited utility in locating users that are not required to register or obtain permits, such as the rural sector, or facilities with a withdrawal capacity below the statutory threshold (100,000 gallons per day in most jurisdictions.) Refer to Figures 5 and 6.

Further research into the ecological impact of water withdrawals should also be a priority. There is evidence that discharge from industrial and thermoelectric plants, while returning water to the basin, alters the thermal and chemical integrity of the lakes. The release of water at a higher than normal temperature has been cited as facilitating the establishment of non-native species (Mills *et al*. 1993). The changes to the flow regime of water, through hydroelectric dams, internal diversions and canals, and

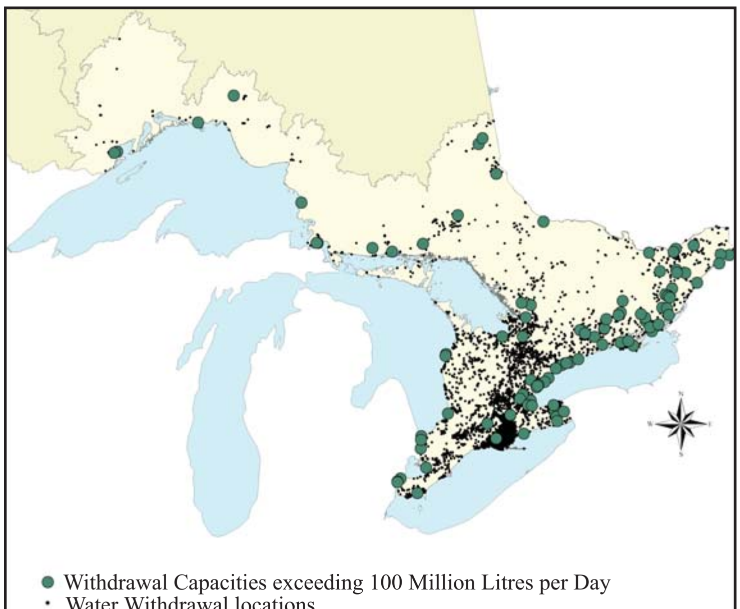

Figure 5. Permitted water withdrawal capacities in the Ontario portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources

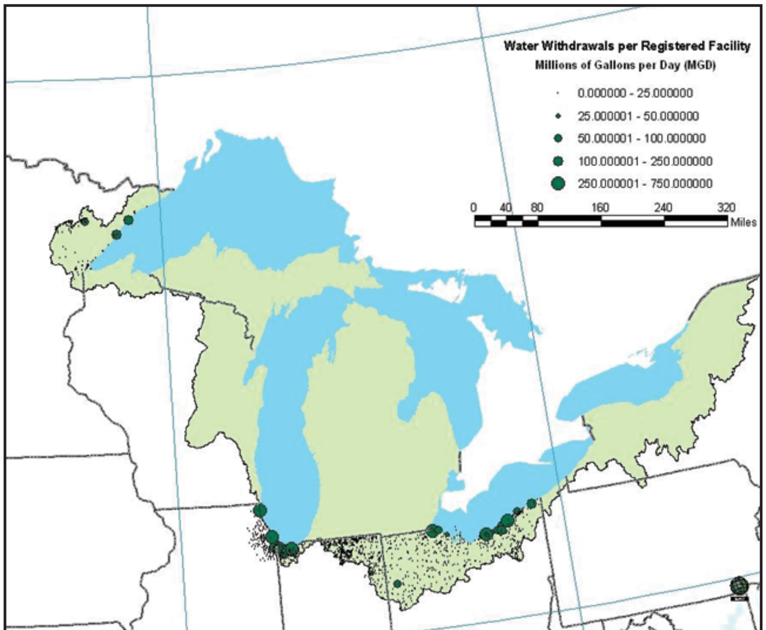

Figure 6. Permitted water withdrawal capacities in the Ontario portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources

other withdrawal mechanisms, may be impairing the health of aquatic ecosystems. Reductions in groundwater discharge, meanwhile, may have negative impacts on Great Lakes surface water quality. Energy is also required for the process of withdrawing, treating and transporting water. These preliminary findings oblige a better understanding of how the very act of withdrawing water, regardless of whether the water is ultimately returned to the basin, can affect the larger ecosystem.

Last Updated
State of the Great Lakes 2005

Energy Consumption
Indicator #7057

Assessment: Mixed, Trend Not Assessed

Purpose
- To assesses the energy consumed in the Great Lakes basin per capita; and
- To infer the demand for resource use, the creation of waste and pollution, and stress on the ecosystem.

Ecosystem Objective
Sustainable development is a generally accepted goal in the Great Lakes basin. Resource conservation minimizing the unnecessary use of resources is an endpoint for ecosystem integrity and sustainable development. This indicator supports Annex 15 of the Great Lakes Water Quality Agreement.

State of the Ecosystem
Energy use per capita and total consumption by the commercial, residential, transportaion, industrial, and electricity sectors in the Great Lakes basin can be calculated using data extracted from the Comprehensive Energy Use Database (Natural Resources Canada), and the State Energy Data 2000 Consumption tables (U.S. EIA 2000). Table 1 lists populations and total consumption in the Ontario and U.S. basins, with the U.S. basin broken down by states. For this report, the U.S. side of the basin is defined as the portions of the eight Great Lakes states within the basin boundary (which totals 214 counties either completely or partially within the basin boundary). The Ontario basin is defined by eight sub-basin watersheds. The most recent data available are from 2002 for Ontario and 2000 for the U.S. The largest change between 2000 and 2002 energy consumption by sector in Ontario was a 4.4% increase in the commercial sector (all other sectors changed by less than 2% in either direction).

In Ontario, the per capita energy consumption increased by 2% between 1999 and 2000. In the U.S. basin, per capita consumption decreased by an average of 0.875% from 1999 to 2000. Five states showed decreases in per capita energy consumption, while three states had increases (Figure 1). Electrical energy consumption per capita was fairly similar on both sides of the basin in 2000 (Figure 2). Over the last four decades, consumption trends in the U.S. basin have been fairly steady, although per capita consumption increased in each state from 1990 to 2000 (Figure 3). Interestingly, New York and Ohio consumed less per capita in 2000 than in 1970. Looking at the trends in Ontario from 1970 to 2000, the per capita energy consumption has stayed relatively consistent, with the exception of an increase seen in 1980. The per capita energy consumption figures for Ontario do not include the electricity generation sector due to an absence of data for this sector up until 1978. It is important to note that the quality of data processing and validation has improved over the last four decades and therefore the data quality may be questionable for the 1970s.

Total secondary energy consumption by the five sectors on the

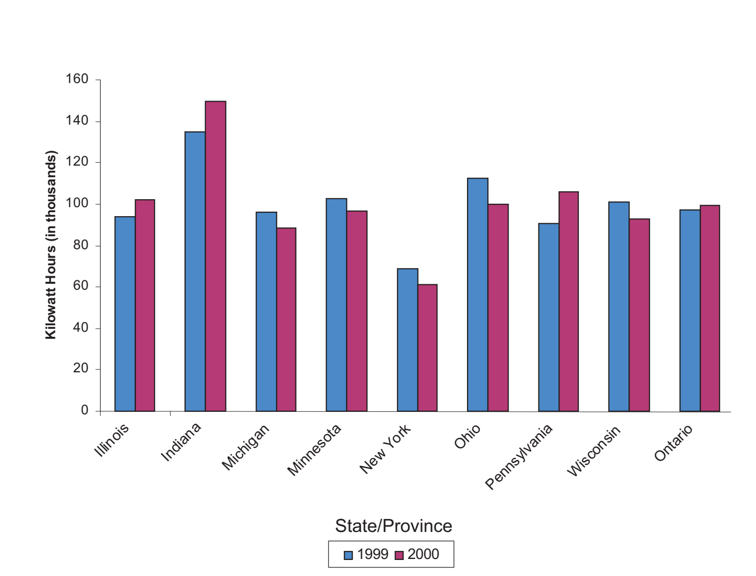

Figure 1. Total energy consumption per capita 1999-2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

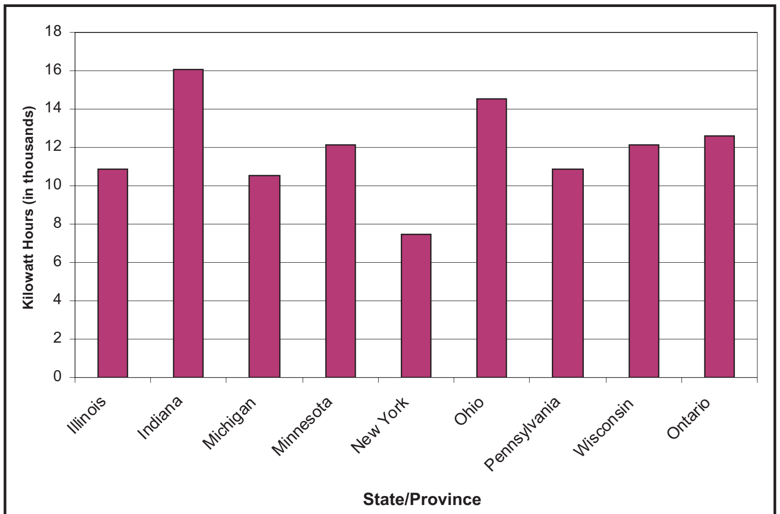

Figure 2. Electric energy consumption per capita 2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

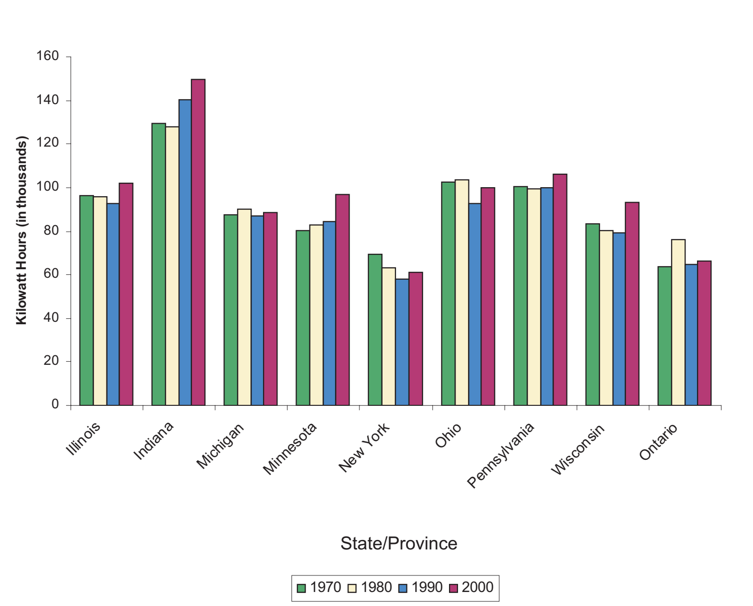

Figure 3. Total per capita energy consumption 1970-2000.1 MWh = 1000 kWh. Other energy sources include geothermal, wind, photovoltaic and solar energy. The Ontario data do not include the electricity generation sector due to an absence of data for this sector until 1978.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

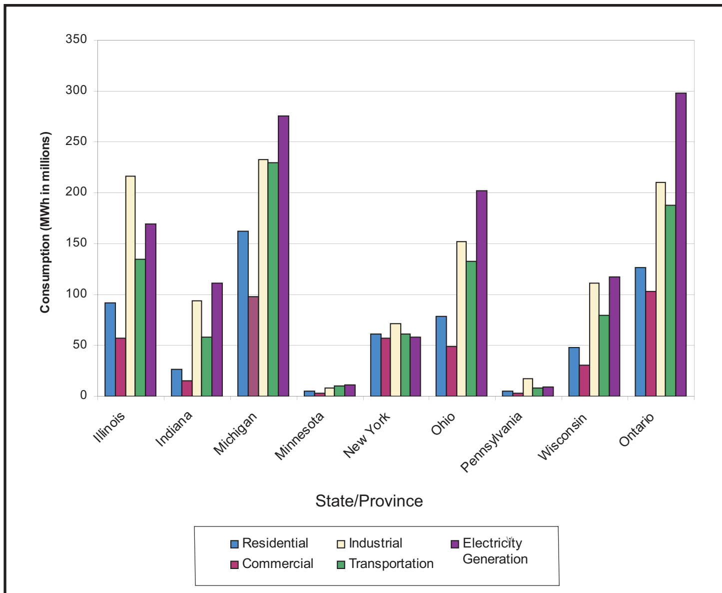

Figure 4. Secondary energy consumption within the Great Lakes basin by sector. Note: all data are from 2000, although 2002 data from Ontario are discussed in the report.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

Canadian side of the basin in 2002 was 930,400,000 Megawatts-hours (MWh) (Table 1). Secondary energy is the energy used by the final consumer. It includes energy used to heat and cool homes and workplaces, and to operate appliances, vehicles and factories. It does not include intermediate uses of energy for transporting energy to market or transforming one energy form to another, this is primary energy. Accounting for 33% of the total secondary energy consumed in the Canadian basin, electricity generation was the largest end user of all the sectors. The other four sectors account for the remaining energy consumption as follows: industrial, 22%; transportation 20%; residential, 15%; and commercial, 12% (Table 2). Note that due to rounding, these figures do not add up to 100. There was a 0.5% increase in total energy consumption by all sectors in Ontario between 2000 and 2002.

Total secondary energy consumption by the five sectors on the U.S. side of the basin in 2000 was 3,364,000,000 MWh (Table 1). As in the Canadian basin, electricity generation was the largest consuming sector in the U.S. basin, using 28% of the total secondary energy in the U.S. side of basin. The U.S. industrial sector consumed only slightly less energy, 27% of the total. The remaining three U.S. sectors account for 44% of the total, as follows: transportation, 21%; residential, 14%; and commercial, 9% (Table 2). Note that due to rounding, these percentages do not add up to 100. Figure 4 shows the total energy consumption by sector for both the Ontario and U.S. sides of the Great Lakes basin in 2000.

State/Province	Total energy consumption by State/Province within the Great Lakes basin (MWh)	Population within the Great Lakes basin*
Ontario (2002 data)	930,400,000	9,912,707
U.S. Basin Total (2000 data)	3,364,000,000	31,912,867
Illinois (IL)	669,400,000	6,025,752
Indiana (IN)	304,900,000	1,845,344
Michigan (MI)	998,500,000	9,955,795
Minnesota (MN)	36,600,000	334,444
New York (NY)	309,600,000	4,506,223
Ohio (OH)	614,000,000	5,325,696
Pennsylvania (PA)	43,700,000	389,210
Wisconsin (WI)	387,300,000	3,530,403

* The U.S. side of the basin is defined as the portions of the 8 Great Lakes states within the basin boundary (which totals 214 counties either completely or partially within the basin boundary).

Table 1: Energy consumption and population within the Great Lakes basin, by state for the year 2000 (U.S.) and 2002 (Ontario). The U.S. basin population was calculated from population estimates by counties (either completely or partially within the basin) from the 2000 U.S. Census (U.S. Census Bureau 2000). Ontario basin populations were determined using sub-basin populations provided by Statistics Canada.
Source: U.S. Energy Information Administration and Natural Resources Canada

Sector	U.S. Basin Total Energy Consumption - 2000*	Canadian Basin Total Energy Consumption - 2002
Residential	478,200,000	127,410,000
Commercial	314,300,000	107,800,000
Industrial	903,900,000	206,410,000
Transportation	714,000,000	184,950,000
Electricity Generation	953,600,000	303,830,000

* Note: 2000 is the most recent data available on a consistent basis for the U.S. More recent data is available for some energy sources from the EIA, but survey and data compilation methods may vary.

Table 2: Total Secondary Energy Consumption in the Great Lakes basin, in Megawatts-hours (MWh).
Source: U.S. Energy Information Administration and Natural Resources Canada

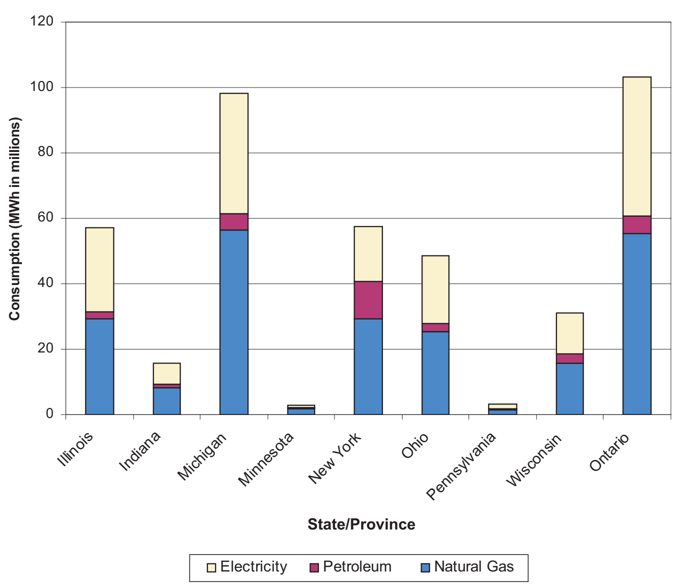

Figure 5. Commercial sector energy consumption by source, 2000. Wood and coal were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

The commercial sector includes all activities related to trade, finance, real estate services, public administration, education, commercial services (including tourism), government and institutional living and is the smallest energy consumer of all the sectors in both Canada and the U.S. (Table 2). Of the total secondary energy use by this sector in the Ontario basin, 57% of the energy consumed was supplied by fossil fuel (natural gas, 50%; and petroleum, 7%) and 43% was supplied by electricity. In Ontario, this sector had the largest increase in total energy consumption, 4.4%, between 2000 and 2002. By source, on the U.S. side of the basin, 61% was supplied by fossil fuel (natural gas, 53%; and petroleum, 8%) and 39% was supplied by electricity. On both sides of the basin, the commercial sector had the highest proportion of electricity use of any sector. Figure 5 shows energy consumption by source for the commercial sector for the Canadian and the U.S. basins in 2000.

The residential sector includes four major types of dwellings: single detached homes, single attached homes, apartments and mobile homes, and excludes all institutional living facilities. Fossil fuels (natural gas, petroleum, and coal) are the dominant energy source for residential energy requirements in the Great Lakes basin. Of the total secondary energy use by the residential sector in the Ontario basin in 2002 (Table 2), the source for 67% of the energy consumed was supplied by fossil fuel (natural gas, 61%; and petroleum, 6%), 30% by electricity and 3% by wood (Figure 6).

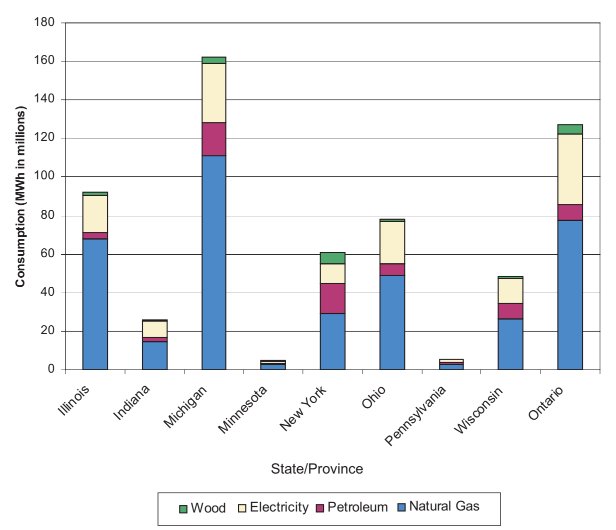

Figure 6. Residential sector energy consumption by source, 2000. Coal, geothermal, and solar energy were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

There was a 0.3% increase in total energy consumption by the Ontario residential sector between 2000 and 2002. On the U.S. side of the basin, fossil fuels are the leading source of energy accounting for 75% of the total residential sector consumption. Natural gas and petroleum are both consumed by this sector, but it is important to note that this sector has the highest natural gas consumption of all five sectors. The remaining energy sources were electricity, 22% and wood, 3% (Figure 6).

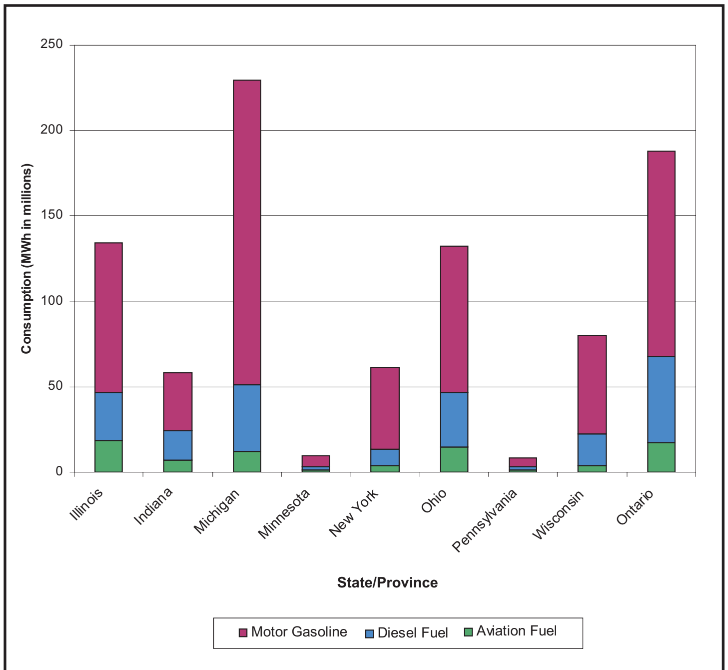

Figure 7. Transportation sector energy consumption by source, 2000. Natural gas and electricity were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

The transportation sector includes activities related to the transport of passengers and freight by road, rail, marine and air. Off-road vehicles, such as snowmobiles and lawn mowers, and non-commercial aviation are included in the total transportation numbers. On both sides of the basin, 100% of the total secondary energy consumed by the transportation sector (Table 2) was supplied by fossil fuel, specifically petroleum. Motor gasoline was the dominant form of petroleum consumed, making up 67% of the Ontario basin total and 70% of the U.S. basin total. This was followed by diesel fuel, 27% in Ontario and 21% in the U.S., and aviation fuel, 6% in Ontario and 9% in the U.S. Figure 7 shows energy consumption by source for the Canadian and U.S. transportation sector in 2000, which had a decrease of 1.7% in total energy consumption on the Canadian side between 2000 and 2002.

The industrial sector includes all manufacturing industries, metal and non-metal mining, upstream oil and gas, forestry and construction, and on the U.S. side of the basin also accounts for agriculture, fisheries and non-utility power producers. On the Canadian side, in 2000, 71% of the energy consumed by this sector was supplied by fossil fuel (natural gas, 35%; petroleum, 20%; and coal, 16%), 19% was supplied by electricity, and the remaining 10% was supplied by wood. Between 2000 and 2002, consumption by industry in Ontario decreased by 1.8%. In addition to these energy sources, steam was a minor contributor to the total energy consumption.

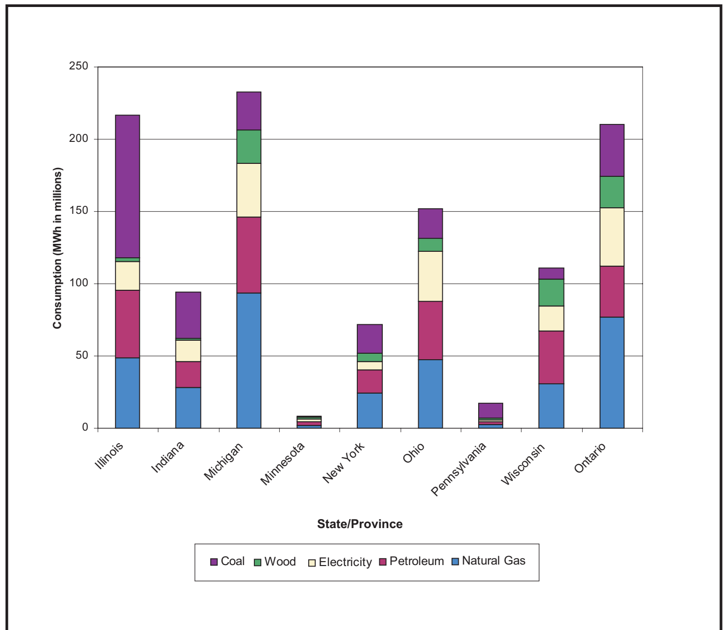

Figure 8. Industrial sector energy consumption by source, 2000. Hydroelectric power was a minor source in this sector. U.S. data for wood include wood waste.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

For the same sector, on the U.S. side of the basin, fossil fuels were the dominant energy source contributing 79% of the total energy (natural gas, 31%; coal, 24 %; and petroleum, 24%). The remaining sources were electricity, at 15%, and wood/wood waste, at 7%. Figure 8 shows energy consumption by source for the industrial sector on both the Canadian and U.S. sides of the basin in 2000. It is important to note that the numbers given for the Ontario industrial sector are likely underestimations of the total energy consumption on the Canadian side of the basin. Numbers were estimated using the population of the Canadian side of the basin as a proportion of the total population of Ontario, this results in an estimation of 87% of total industrial energy use in Ontario being contained within the basin. However, Statistics Canada estimates that as much as 95% of industry in Ontario is contained within the basin. Estimating by population was done to remain consistent with the data provided for the U.S. side of the basin.

The last, and the largest consuming sector in both the Canadian and the U.S. basins, is the electricity generation sector. Of the total secondary energy use in the Ontario basin (Table 2), 67% of the energy consumed by this sector was supplied by nuclear energy, 26% was supplied by fossil fuel (coal, natural gas and

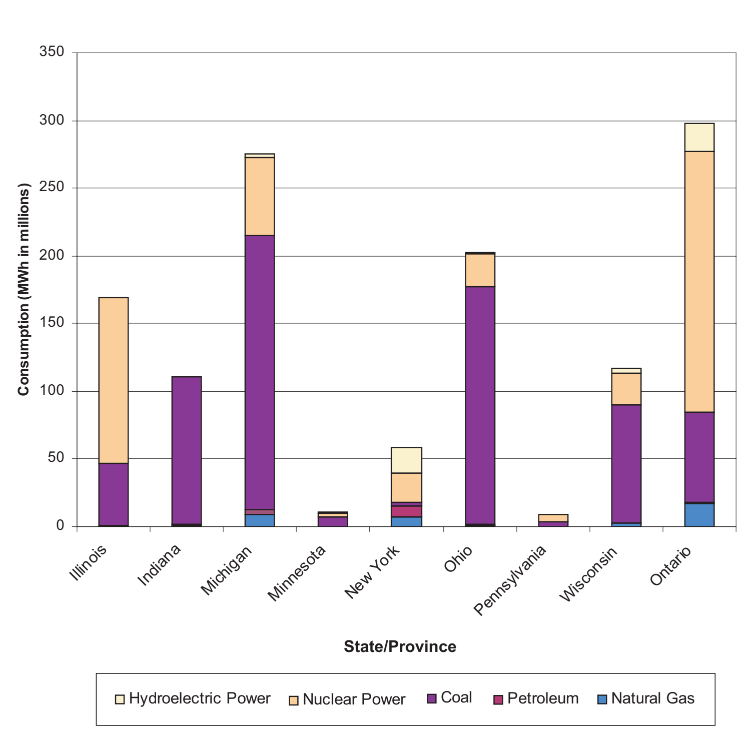

Figure 9. Electricity generation sector energy consumption by source, 2000. Wood and wood waste were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

petroleum), and 7% was supplied by hydroelectric energy. There was an increase in total energy use of 1.9% between 2000 and 2002 in Ontario. It is important to note that the Great Lakes basin contains the majority of Canada's nuclear capacity. Of the total secondary energy use by this sector in the U.S. basin (Table 2), 70% was supplied by the following types of fossil fuel: coal (66%), natural gas (2%), and petroleum (2%). The other two major sources, nuclear and hydroelectric energy, provided 27% and 3% respectively. This sector consumed 75% of the coal used in the entire U.S. basin. Figure 9 shows energy consumption by source for the electricity generation sector for the Canadian and U.S. sides of the basin in 2000.

The overall trends in energy consumption by sector were quite similar on both sides of the basin. Ranked from highest to lowest energy consumption, the pattern for the sectors was the same for the U.S. and Canadian basins (Table 2). Analyses of the sources of energy within each sector and trends in resources consumption also indicate very similar trends.

Pressures

In 2001, Canada was ranked as the fifth largest energy producer and the eighth largest energy consuming nation in the world. Comparatively, the United States is ranked as "the world's largest energy producer, consumer, and net importer" (U.S. EIA 2004). The factors responsible for the high energy consumption rates in Canada and the U.S. can also be attributed to the Great Lakes basin. These include a high standard of living, a cold climate, long travel distances, and a large industrial sector. The combustion of fossil fuels, the dominant source of energy for most sectors in the basin, releases greenhouse gases such as carbon dioxide and nitrous oxide into the air contributing to smog, climate change, and acid rain.

Canada's Energy Outlook 1996-2020 (http://nrn1.nrcan.gc.ca:80/es/ceo/toc-96E.html) notes that "a significant amount of excess generating capacity exists in all regions of Canada" because demand has not reached the level predicted when new power plants were built in the 1970s and 1980s. Demand is projected to grow at an average annual rate of 1.3 percent in Ontario and 1.0 percent in Canada overall between 1995 and 2020. From 2010-2020, Ontario will add 3,650 megawatts of new gas-fired and 3,300 megawatts of clean coal-fired capacity. Several hydroelectric plants will be redeveloped. Renewable resources are projected to quadruple between 1995 and 2020, but will contribute only 3 percent of total power generation.

The pressures the U.S. currently faces will continue into the future, as the U.S. works to renew its aging energy infrastructure and develop renewable energy sources. Over the next two decades, U.S. oil consumption is estimated to grow by 33%, and natural gas consumption will increase by more than 50%. Electricity demand is forecast to increase by 45% nationwide (National Energy Policy 2001). Natural gas demand currently outstrips domestic production in the U.S. with imports (largely from Canada) filling the gap. 40% of the total U.S. nuclear output is generated within five states, including three within the Great Lakes basin (Illinois, Pennsylvania, and New York) (U.S. EIA 2004). Innovation and creative problem solving will be needed to work towards balancing economic growth and energy consumption in the Great Lakes basin in the future.

Management Implications

Natural Resources Canada, Office of Energy Efficiency has implemented several programs that focus on energy efficiency and conservation within the residential, commercial, industrial, and transportation sectors. Many of these programs work to provide consumers and businesses with useful and practical information regarding energy saving methods for buildings, automobiles, and homes. The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy recently launched an educational website (http://www.eere.energy.gov/consumerinfo/), which provides homes and businesses with ways to improve efficiency, tap into renewable and green energy supplies, and reduce energy costs. In July 2004, Illinois, Minnesota, Pennsylvania, and Wisconsin were awarded $46.99 million to weatherize low-income homes, which is expected to save energy and cost (EERE 2004). The U.S. Environmental Protection Agency Energy Star program, a government/industry partnership initiated in 1992, also promotes energy efficiency through product certification. In 2002, Americans saved more than $7 billion in energy costs through Energy Star, while consuming less power and preventing greenhouse gas emissions (USEPA 2003).

In addition to these programs, the Climate Change Plan for Canada challenges all Canadians to reduce their greenhouse gas emissions by one tonne, approximately 20% of the per capita production on average each year. The One-Tonne Challenge offers a number of ways to reduce the greenhouse gas emissions that contribute to climate change and in doing so will also reduce total energy consumption.

Renewable energy sources such as solar and wind power are available in Canada, but constitute only a fraction of the total energy consumed. Research continues to develop these as alternate sources of energy, as well as developing more efficient ways of burning energy. In the United States, according to the U.S. Energy Information Administration, 6% of the total 2002 energy consumption came from renewable energy sources (biomass, 47%; hydroelectric, 45%; geothermal, 5%; wind, 2%; and solar, 1%). The U.S. has invested almost a billion dollars, over three years, for renewable energy technologies (Garman 2004). Wind energy, cited as one of the fastest growing renewable sources worldwide, is a promising source for the Great Lakes region. The U.S. Department of Energy, its laboratories, and state programs are working to advance research and development of renewable energy technologies.

Acknowledgments
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Authors' Commentary
Ontario data are available through Natural Resources Canada, Office of Energy Efficiency. Databases include the total energy consumption for the residential, commercial, industrial, transportation, agriculture and electricity generation sectors by energy source and end use. Population numbers for the Great Lakes basin, provided by Statistics Canada, were used to calculate the

energy consumption numbers within the Ontario side of the basin. This approach for the residential sector should provide a reasonable measure of household consumption. For the commercial, transportation and especially industrial sectors, it may be a variable estimation of the total consumption in the basin. The data are provided on nation-wide, or province-wide basis. Therefore it provides a great challenge to disaggregate it by any other methods to provide a more precise representation of the Great Lakes basin total energy consumption.

Energy consumption, price, and expenditure data are available for the United States (1960-2000) through the Energy Information Administration (EIA). The EIA is updating the State Energy Data 2000 series to 2001 by August 2004. There may be minor discrepancies in how the sectors were defined in the U.S. and Canada, which may need further investigation (such as tourism in the U.S. commercial sector, and upstream oil and gas in the U.S. industrial sector). Actual differences in consumption rates may be difficult to distinguish from minor differences between the U.S. and Canada in how data were collected and aggregated. Hydroelectric energy was not included in the industrial sector analysis, but might be considered in future analyses. In New York State, almost as much energy came from hydroelectric energy as from wood. Wisconsin and Pennsylvania also had small amounts of hydropower consumption.

In the U.S. the current analysis of the total basin consumption is based on statewide per capita energy consumption, multiplied by the basin population. The ideal estimate of this indicator would be to calculate the per capita consumption within the basin, and would require energy consumption data at the county level or by local utility reporting areas. Such data may be quite difficult to obtain, especially when electricity consumption per person is reported by utility service area. The statewide per capita consumption may be different than the actual per capita consumption within the basin, especially for the states with only small areas within the basin (Minnesota and Pennsylvania). The proportion of urban to rural/agricultural land in the basin is likely to influence per capita consumption within the basin. Census data are available at the county and even the block level, and may in the future be combined with the U.S. basin boundary using GIS to refine the basin population estimate.

Additionally, the per capita consumption data for the U.S. in Figures 1, 2, and 3 are based on slightly different energy consumption totals than the data in Tables 1 and 2. The next update of this indicator should examine whether it is worthwhile to include the minor sources in the sector analysis on both sides of the basin or to exclude them from the per capita figures.

Last Updated

State of the Great Lakes 2005

Solid Waste Disposal
Indicator #7060

Overall Assessment

Status:	**Trend Not Assessed**
Trend:	**Undetermined**
Primary Factors Determining Status and Trend	**This year the indicator report focuses only on disposal data in the U.S. instead of generation or recycling data. Disposal data was the most consistently collected by the counties/states in the U.S. Generation and recycling data were available for Ontario, Canada. Over time, a change in disposal tonnages can be used as an indicator for solid waste in the Great Lakes, however more consistent and comparable data would improve this indicator.**

Lake-by-Lake Assessment
Due to insufficient data, a lake-by-lake assessment is not available for this indicator.

Purpose
•To assess the amount of solid waste disposed in the Great Lakes basin; and
•To infer inefficiencies in human economic activity (i.e. wasted resources) and the potential adverse impacts to human and ecosystem health.

Ecosystem Objective
Solid waste provides a measure of the inefficiency of human land based activities and the degree to which resources are wasted. In order to promote sustainable development, the amount of solid waste disposed of in the basin needs to be assessed and ultimately reduced. Because a portion of the waste disposed of in the basin is generated outside of basin counties, efforts to reduce waste generation or increase recycling need to occur regionally. Reducing volumes of solid waste via source reduction or recycling is indicative of a more efficient industrial ecology and a more conserving society. This indicator supports Annex 12 of the Great Lakes Water Quality Agreement (United States and Canada 1987).

State of the Ecosystem
Canada and the United States are working towards improvements in waste management by developing strategies to prevent waste generation and reuse and recycle more of the generated waste. The data available to support this indicator are limited in some areas of the basin and not consistent from area to area. For example, while most of the U.S. states in the basin track amount of waste disposed in a landfill or incinerator located in a county, they may define the wastes differently. Some track all non-hazardous waste disposed and some only track municipal solid waste. Because the wastes disposed of in each county in the basin were not necessarily generated by the county residents, per capita estimates are not meaningful. Not all of the U.S. counties provide generation and recycling rates information. Canada provides estimates of waste generation rate for each of its Provinces for residential, industrial/commercial, and construction and demolition sources. The summary statistics report also provided disposal data, however the disposal data included wastes that were disposed of outside the Province, some of which is captured in the U.S. county disposal data within the basin. For this reason, generation and

diversion estimates were used only for Ontario, Canada; disposal data were used for the U.S. counties. Types of waste included in the disposal data are identified below.

Statistics for the generation of waste in Ontario were gathered from the Annual Statistics 2005 report. More than 11 million tonnes of wastes were generated in Ontario in 2000 and slightly more than 12 million tonnes were generated in 2002. These figures include residential wastes, commercial/industrial wastes, and construction and demolition wastes. Diversion information was also provided in the report and can be seen in Figure 1. In 2000, 20.8% of the residential waste generated was diverted to recycling and in 2002 that figure increased to 21.6%. The industrial/commercial recycling rate was 22.7% in 2000 and 20.2% in 2002. Finally, the C&D recycling rate was 11.6% in 2000 and 12.5% in 2002. Ontario has a goal to divert 60% of its waste by 2008.

Minnesota Great Lakes basin counties provided data on the amounts of waste disposed of in the county as well as an estimate of the amount of waste buried by residents (on their own property). Data are provided in Figure 2. In 2003, 124,931 tons of waste were disposed of or buried in the 7 basin counties in MN. In 2004, there was a 5% increase to 132,128 tons disposed or buried. Each county showed an increase in waste disposed. These figures only include municipal solid waste (not construction and demolition debris or other industrial wastes).

The Indiana Department of Environmental Management's data regarding amounts disposed of at permitted facilities were used to determine the total amount disposed in each Indiana Great Lakes Basin county. The data are provided in Figure 3. The disposal in 2004 was approximately 9% greater than in 2003. The 15 basin counties disposed of 2,468,913 tons of waste in 2004 and 2,224,581 tons in 2005. About 15% was generated outside of the counties in 2004. The data include municipal solid waste, construction and demolition wastes, and some industrial byproduct waste.

The Illinois Environmental Protection Agency, Bureau of Land, reported the amounts disposed of in permitted landfills in the 2 Great Lakes basin counties. Data were compiled for 2004 and 2003 and are shown in Figure 4. There was less than a 2% change in total materials. In 2004 1,814,529 tons were disposed and in 2003 slightly less waste (1,784,452 tons) was disposed. The data include municipal solid waste, construction and demolition waste, and some industrial waste.

The Michigan Department of Environmental Quality reports on total waste disposed in Michigan landfills in cubic yards. General conversion factors (to translate cubic yards to tons) could not be used because the waste totals include a variety of waste sources (municipal solid waste, construction and demolition debris, and some industrial byproducts). Data for the 83 Great Lakes basin counties were compiled and are presented in Figure 5. There was less than a 1% difference between the total cubic yards disposed in 2004 and 2005 in these counties. The total for 2005 was slightly smaller. For both years, approximately 64 million cubic yards were disposed of in the 83 counties in the Great Lakes Basin.

The New York Department of Environmental Conservation provided municipal solid waste disposal data for facilities located in the 32 Great Lakes basin counties for the years 2004 and

2002. The data are presented in Figure 6. There was an approximate 5% increase in waste disposed. The total waste disposed was 7,853,087 tons in 2004 and 7,333,685 tons in 2002. This data includes municipal solid waste only. More than 65% of the states waste is managed in the basin counties.

The Pennsylvania Department of Environmental Protection provided disposal data for the three Great Lakes basin counties. Municipal solid waste and construction and demolition debris are combined in these annual totals which are presented in Figure 7. For 2004, 282,004 tons were disposed in the three basin counties. There was a 25% decrease in waste disposed in the counties in 2005 to 209,229 tons.

The Wisconsin Department of Natural Resources collects data on the amount disposed of in each facility located in the Great Lakes basin counties. Data were compiled for the 26 basin counties and are presented in Figure 8. In 2005, 7,663,187 tons of wastes were disposed, within 1% of the total disposed in 2004. Totals include a wide variety of wastes such as municipal solid waste, sludges, and foundry sand.

The Ohio Environmental Protection Agency collects data for waste disposed of in landfills and incinerators. The data for the 36 Great Lakes basin counties was compiled for 2003 and 2004 and are presented in Figure 9. There was an approximate 5% increase in waste disposed. More than 60% of these waste disposed in the counties came from outside the counties. The data includes municipal solid waste, some industrial wastes, and tires. Construction and demolition debris is not included. In 2004, the 36 basin counties disposed of 8,791,802 tons and in 2003 8,334,865 tons were disposed.

Pressures

The generation and management of solid waste raise important environmental, economic and social issues for North Americans. Waste disposal costs billions of dollars and the entire waste management process uses energy and contributes to land, water, and air pollution. The U.S. EPA has developed tools and information linking waste management practices to climate change impacts. Waste prevention and recycling reduce greenhouse gases associated with these activities by reducing methane emissions, saving energy, and increasing forest carbon sequestration. Waste prevention and recycling save energy when compared to disposal of materials.

The state of the economy has a strong impact on consumption and waste generation. Municipal solid waste generation in the U.S. continued to increase through the 1990s and has remained steady since 2000 (USEPA 2003). Generation of other wastes, such as construction and demolition debris and industrial wastes is also strongly linked to the economy. The U.S. EPA is developing a methodology to better estimate the generation, disposal, and recycling of construction and demolition debris in the U.S.

Because waste disposed of in the Great Lakes Basin may be generated outside of the Basin or moved around within the Basin, efforts to reduce waste generation and increase recycling need to focus on a broad area, not just the Basin. Continued collaboration of state, local, and federal efforts is important for long term success.

Management Implications

The U.S. EPA supports a bi-annual study that characterizes the municipal solid waste stream and estimates the national recycling rate. The latest study (2003) estimates a 30.6% national recycling rate. The U.S. EPA has established a goal of reaching a 35% recycling rate by 2008. The 2003 study indicated that paper, yard and food waste, and packaging represent large portions of the waste stream. The U.S. EPA's is concentrating its efforts on these materials; working with stakeholders to determine activities that may support increased recovery of those materials. The federal government is also working to promote strategies that support recycling programs in general, including Pay-As-You-Throw (generators pay per unit of waste rather than a flat fee); innovative contracting mechanisms such as resource management (includes incentives for increased recycling), and supporting demonstration projects and research on various end markets and collection strategies for waste materials. The States are also working to increase recycling rates and provide support for local jurisdictions. Each state with counties in the Great Lakes basin provides financial and technical support for local recycling programs. Many provide significant market development support as well.

Canada and the U.S. both support integrated solutions to the waste issue and look for innovative approaches that involve the public and private sectors. Extended Producer Responsibility (EPR), also known as Product Stewardship is one approach that involves manufacturers of products. EPR efforts have focused on many products including electronics, carpets, paints, thermostats, etc.

Ontario's Waste Diversion Act was passed in 2002 and created Waste Diversion Ontario, a permanent, non-government corporation. The Act gave WDO the mandate to develop, implement and operate waste diversion programs-to reduce, reuse or recycle waste.

The City of Toronto has set ambitious waste diversion goals and reported a 40% diversion rate in 2005. The development of a green bin system (allowing residents to separate out the organic fraction of the waste stream from traditional recyclables) is credited for the high diversion rate achieved.

Improved and consistent data collection would help to better inform decisionmakers regarding effectiveness of programs as well as determining where to target efforts.

Comments from the author(s)

During the process of collecting data for this indicator, it was found that U.S. states and Ontario compile and report on solid waste information in different formats. Future work to organize a standardized method of collecting, reporting and accessing data for both the Canadian and U.S. portions of the Great Lakes basin will aid in the future reporting of this indicator and in the interpretation of the data and trends. More consistent data may also support strategic planning.

Acknowledgments
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Data Sources

The United States data regarding national recycling rate and municipal solid waste characteristics was collected from Municipal solid waste in the United States: 2003 facts and figures; available on the U.S. EPA's web site at http://www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm.

Solid waste data for Ontario was collected from Human Activity and the Environment. Annual Statistics 2005, Featured Article: Solid Waste in Canada, Catalogue number 16-201XIE, Statistics Canada.

Illinois waste disposal data for the 2 basin counties was compiled from the Illinois Environmental Protection Agency, Bureau of Land's 2004 Landfill Capacity report found on their web site at: http://www.epa.state.il.us/land/landfill-capacity/2004/index.html. The 2 Great Lakes Basin counties are located in Illinois EPA's Region 2.

Indiana waste disposal data for the basin counties were compiled from the Indiana Department of Environmental Management's permitted solid waste facility reports found at http://www.in.gov/idem/programs/land/sw/index.html.

Michigan waste disposal data for the basin counties were compiled from the Michigan Department of Environmental Quality's Annual Report on Solid Waste Landfills. Data from the 2005 and 2004 studies were compiled. The author accessed the data via the Border Center's WasteWatcher web site (http://www.bordercenter.org/wastewatcher/mi-waste.cfm) to more easily search for the appropriate county – level data.

Minnesota municipal solid waste disposal data for the basin counties was compiled from the 2004 and 2003 SCORE data available on the Minnesota Pollution Control Agency's web site at: http://www.moea.state.mn.us/lc/score04.cfm The SCORE report is a report to the Legislature, the main components of this report are to identify and target source reduction, recycling, waste management and waste generation collected from all 87 counties in Minnesota.

New York municipal solid waste disposal data for the basin counties were compiled from New York State Department of Environmental Conservation's capacity data for landfills and waste to energy facilities available on their website at: http://www.dec.state.ny.us/website/dshm/sldwaste/newsw2.htm.

Ohio waste disposal data for the basin counties were compiled from Ohio Environmental Protection Agency's 2003 and 2004 facility data reports which are available on their web site at http://www.epa.state.oh.us/dsiwm/pages/general.html.

Pennsylvania waste disposal data for the basin counties were compiled from the Pennsylvania Department of Environmental Protection, Bureau of Land Recycling and Waste Management's disposal data located on their web site at: http://www.depweb.state.pa.us/landrecwaste/cwp/view.asp?a=1238&Q=464453&landrecwasteNav=|.

Wisconsin municipal solid waste disposal data for the basin counties were compiled from the Wisconsin Department of Natural Resources, Bureau of Waste Management's Landfill Tonnage Report found on their website at:. http://www.dnr.state.wi.us.

United States and Canada. 1987. Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987. Ottawa and Washington.

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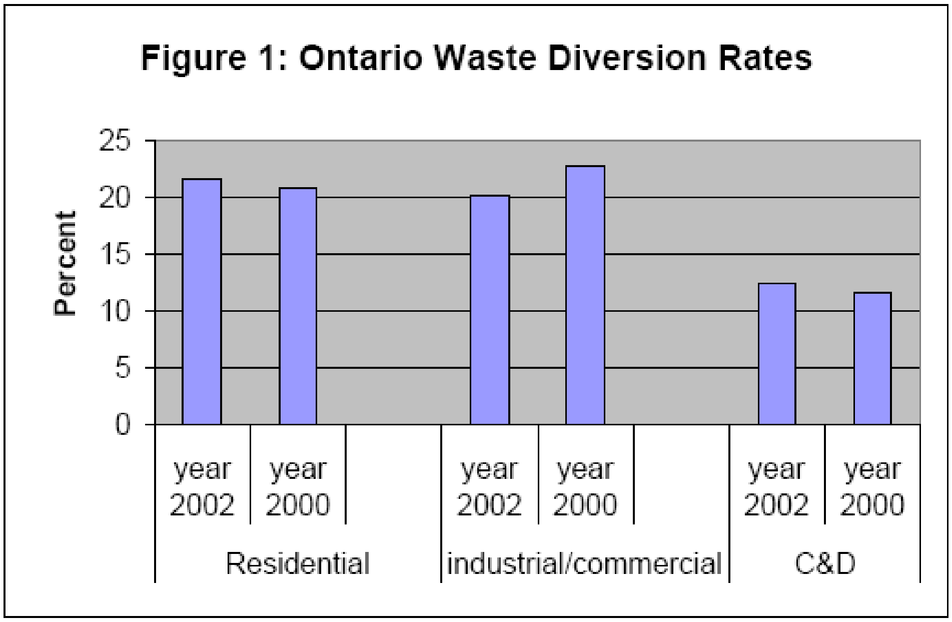

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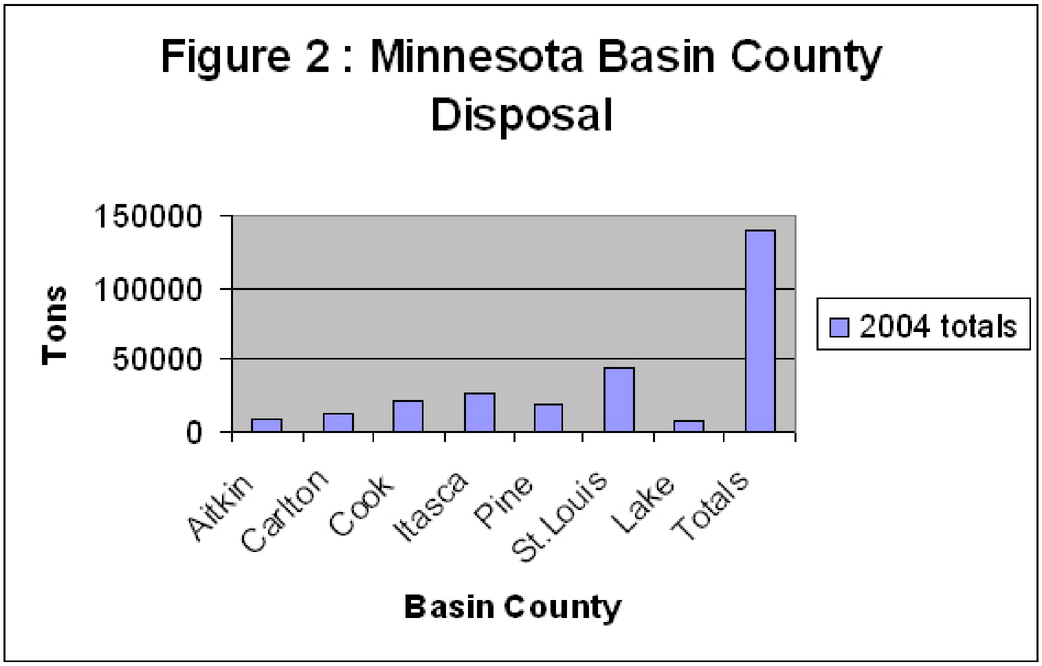

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Source: Minnesota Pollution Control Agency, Score Report, 2003 and 2004.

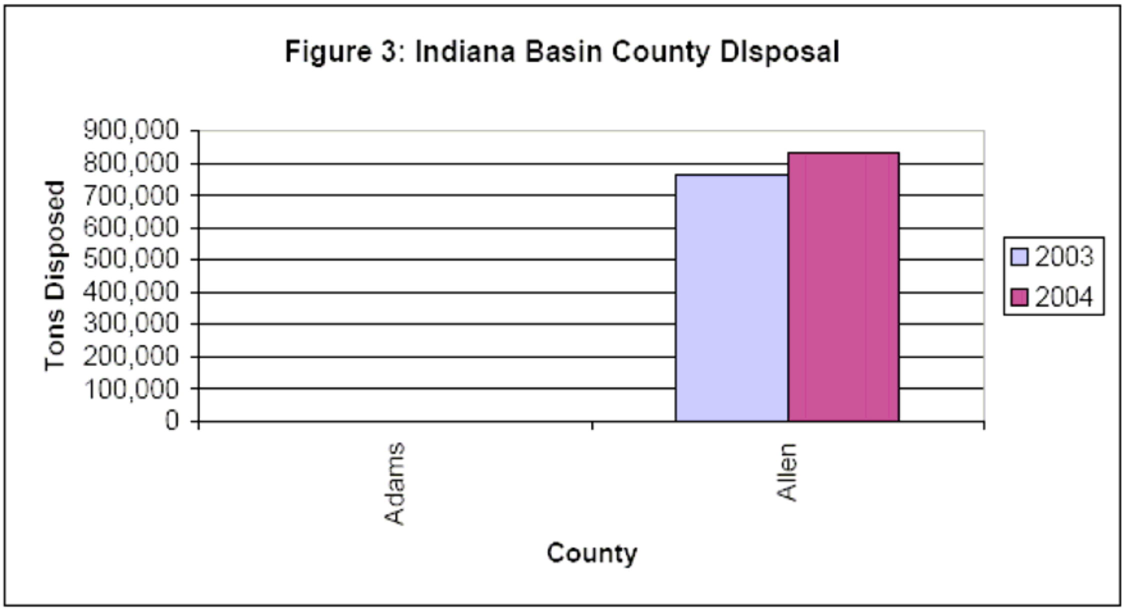

Figure 3. Indiana Basin County Disposal.
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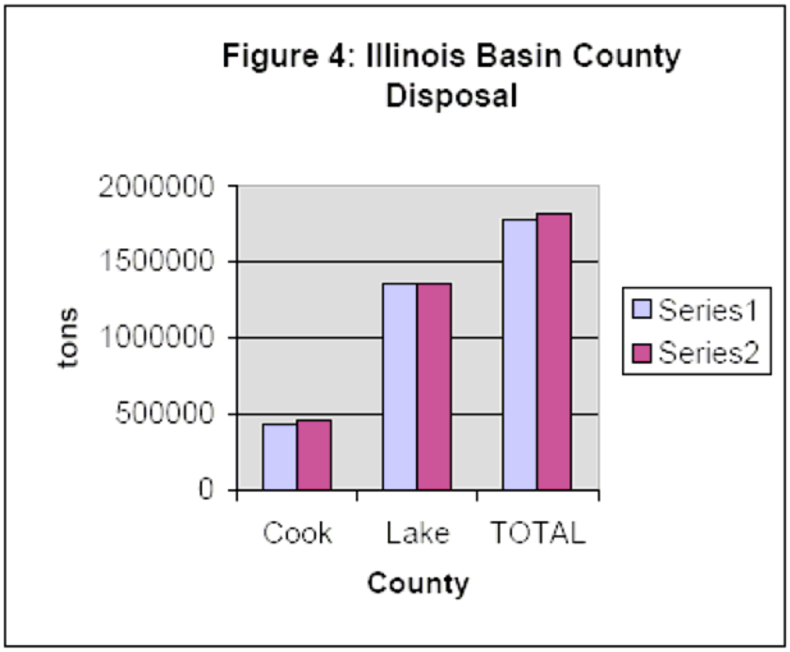

Figure 4. Illinois Basin County Disposal.
Source: Illinois Environmental Protection Agency, 2004 Landfill Capacity Report.

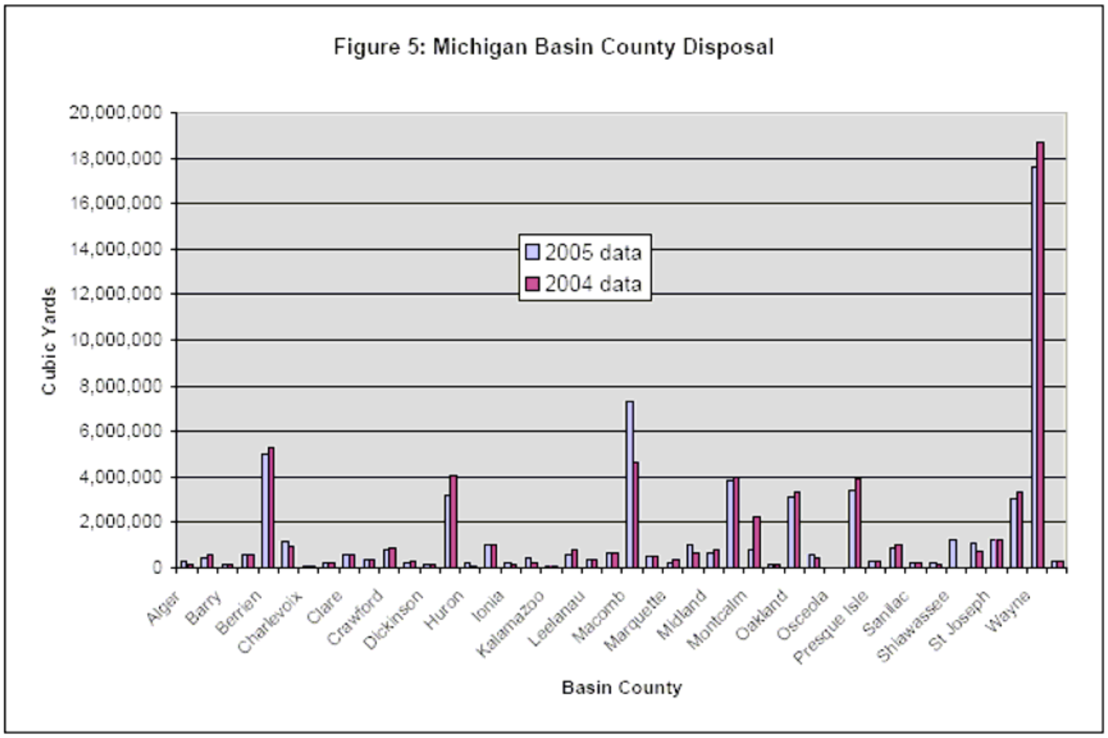

Figure 5. Michigan Basin County Disposal.
Source: Michigan Department of Environmental Quality, 2005 and 2004 Annual Report on Solid Waste Landfills.

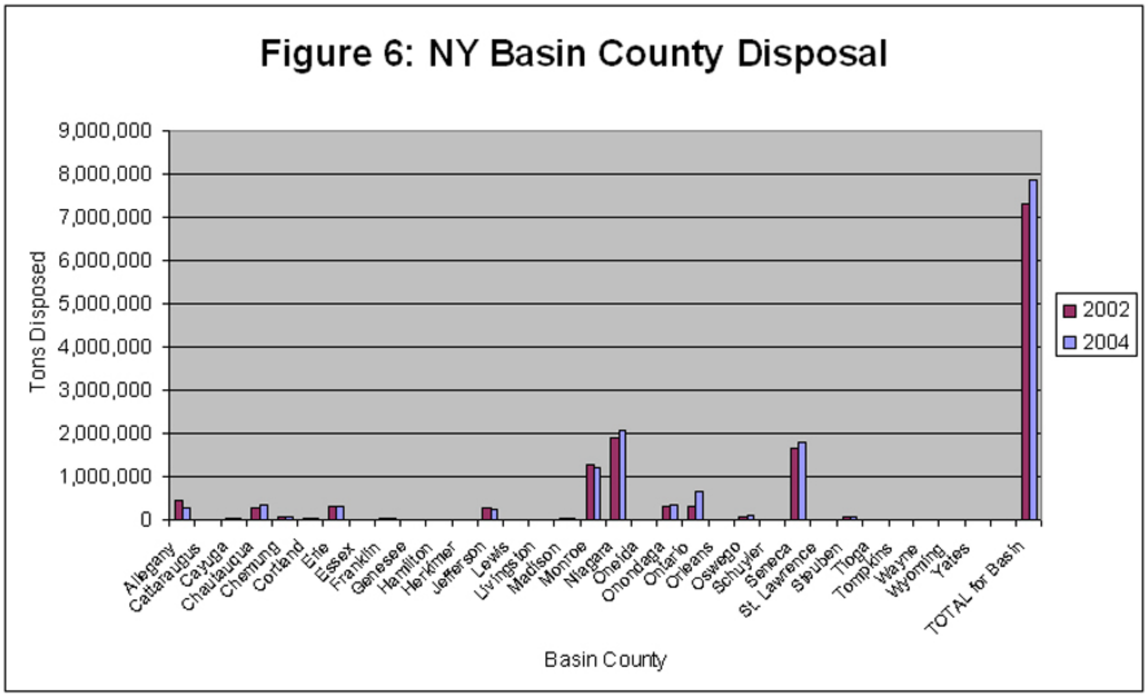

Figure 6. New York Basin County Disposal.
Source: New York State Department of Conservation Capacity data for Landfills and Waste to Energy Facilities.

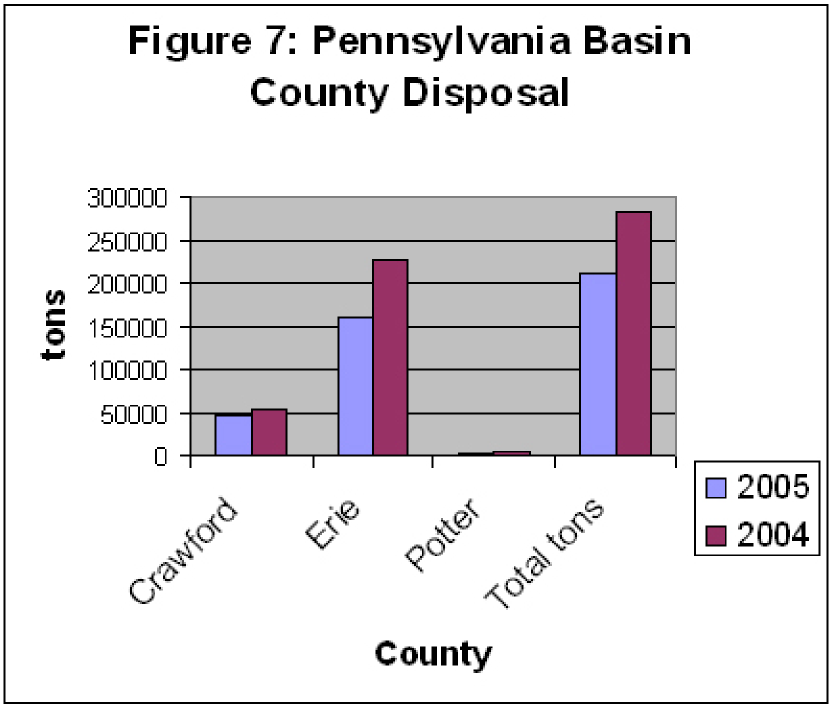

Figure 7. Pennsylvania Basin County Disposal.
Source: Pennsylvania Department of Environmental Protection Landfill Disposal Data.

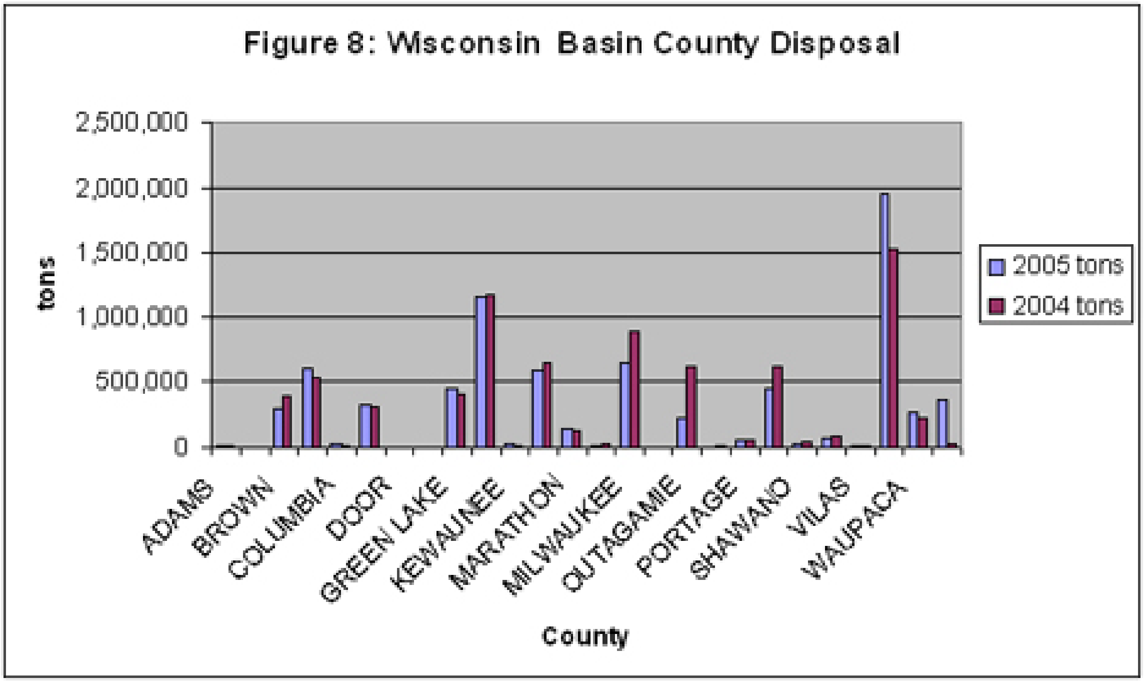

Figure 8 Wisconsin Basin County Disposal
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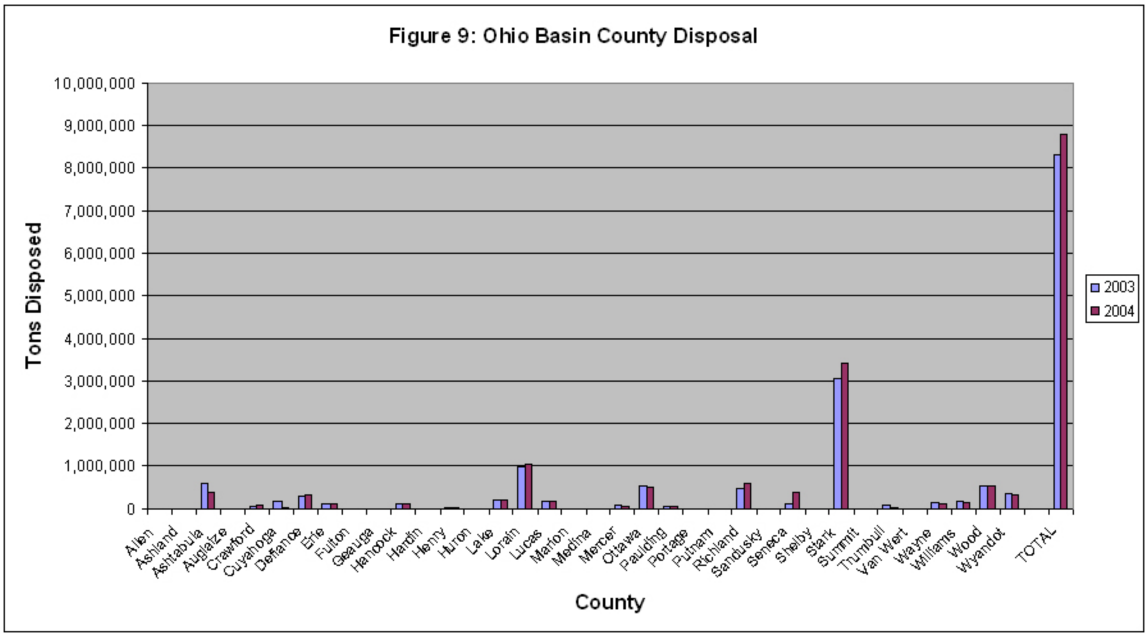

Figure 9. Ohio Basin County Disposal.
Source: Ohio Environmental Protection Agency, 2003 and 2004 Facility Data Reports.

Nutrient Management Plans

Indicator # 7061

Assessment: Not Assessed

Purpose

- To determine the number of Nutrient Management Plans; and
- To infer environmentally friendly practices that help to prevent ground and surface water contamination.

Ecosystem Objective

This indicator supports Annexes 2, 3, 11, 12 and 13 of the Great Lakes Water Quality Agreement. The objective is sound use and management of soil, water, air, plants and animal resources to prevent degradation of the environment. Nutrient Management Planning guides the amount, form, placement and timing of applications of nutrients for uptake by crops as part of an environmental farm plan.

State of the Ecosystem

Background

Given the key role of agriculture in the Great Lakes ecosystem, it is important to track changes in agricultural practices that can lead to protection of water quality, the sustainable future of agriculture and rural development, and better ecological integrity in the basin. The indicator identifies the degree to which agriculture is becoming more sustainable and has less potential to adversely impact the Great Lakes ecosystem. As more farmers embrace environmental planning over time, agriculture will become more sustainable through nonpolluting, energy efficient technology and best management practices for efficient and high quality food production.

Status of Nutrient Management Plans

The Ontario Environmental Farm Plans (EFP) identify the need for best nutrient management practices. Over the past 5 years farmers, municipalities and governments and their agencies have made significant progress. Ontario Nutrient Management Planning software (NMAN) is available to farmers and consultants wishing to develop or assist with the development of nutrient management plans.

In 2002 Ontario passed the Nutrient Management Act (NM Act) to establish province-wide standards to ensure that all land-applied materials will be managed in a sustainable manner resulting in environmental and water quality protection. The NM Act requires standardization, reporting and updating of nutrient management plans through a nutrient management plan registry. To promote a greater degree of consistency in by-law development, Ontario developed a model nutrient management by-law for municipalities. Prior to the NM Act, municipalities enforced each nutrient management by-law by inspections performed by employees of the municipality or others under authority of the municipality.

In the United States, the two types of plans dealing with agriculture nutrient management are the Comprehensive Nutrient Management Plans (CNMPs) and the proposed Permit Nutrient Plans (PNP) under the U.S. Environmental Protection Agency's (USEPA) National Pollution Discharge Elimination System (NPDES) permit requirements. Individual States also have additional nutrient management programs. An agreement between USEPA and U.S. Department of Agriculture (USDA) under the Clean Water Action plan called for a Unified National Strategy for Animal Feeding Operations. Under this strategy, USDA-Natural Resources Conservation Service has leadership for the development of technical standards for CNMPs. Funds from the Environmental Quality Incentives Program can be used to develop CNMPs.

The total number of nutrient management plans developed annually for the U.S. portion of the basin is shown in Figure 1. This includes nutrient management plans for both livestock and non-livestock producing farms. The CNMPs are tracked on an annual

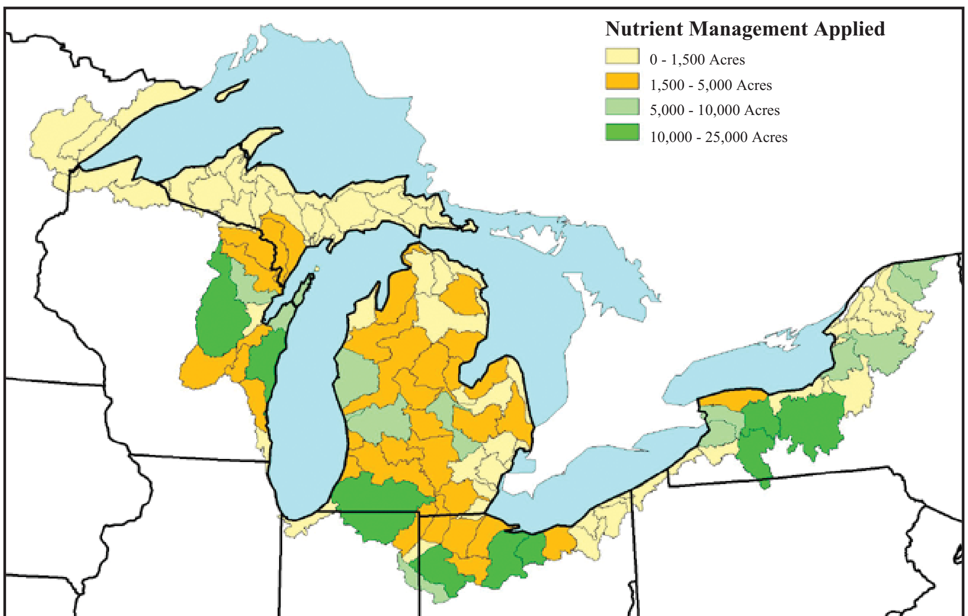

Figure 1. Annual U.S. Nutrient Management Systems total number of nutrient management plans developed annually for the U.S. portion of the basin, 2003.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Performance and Results Measurement System

basis due to the rapid changes in farming operations. This does not allow for an estimate of the total number of CNMPs. USEPA will be tracking PNP as part of the Status's NPDES program.

Figure 2 shows the number of Nutrient Management Plans by Ontario County for the years 1998-2002, and Figure 3 shows cumulative acreage of Nutrient Management Plans for the Ontario portion of the basin. The Ontario Nutrient Management Act is moving farmers toward the legal requirement of having a nutrient management plan in place. Prior to 2002 the need for a plan was voluntary and governed by municipal by-laws. The introduction of the Act presently requires new, expanding, and existing large farms to have a nutrient management plan. This has brought the expectation, which is reflected in Figure 2, that there will be on-going needs to have nutrient management plans in place.

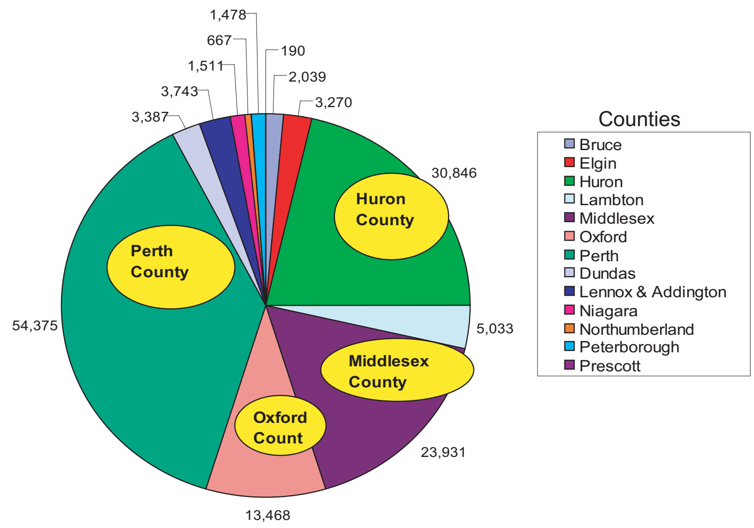

Figure 3. Cumulative acreage of Nutrient Management Plans for selected Ontario Counties in the basin. Over 75% NMP acreages found in Huron, Perth, Oxford and Middlesex Counties.
Source: Ontario Ministry of Agriculture and Food

Having completed a NMP provides assurance farmers are considering the environmental implications of their management decisions. The more plans in place the better. In the future there may be a way to grade plans by impacts on the ecosystem. The first year in which this information is collected will serve as the base line year

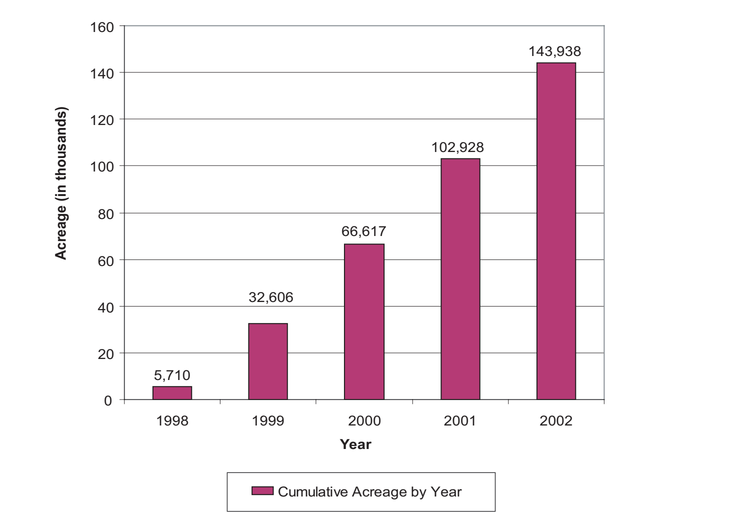

Figure 2. Nutrient Management Plans by Ontario County, 1998-2002.
Source: Ontario Ministry of Agriculture and Food

Pressures

As livestock operations consolidate in number and increase in size in the basin, planning efforts will need to keep pace with changes in water and air quality standards and technology. Consultations regarding the provincial and U.S. standards and regulations will continue into the near future.

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Roger Nanney, Resource Conservationist, U.S. Department of Agriculture, Natural Resource Conservation Service.

Authors' Commentary

The new Nutrient Management Act authorizes the establishment and phasing in of province-wide standards for the management of materials containing nutrients and sets out requirements and responsibilities for farmers, municipalities and others in the business of managing nutrients. It is anticipated that the regulations under this act will establish a computerized NMP registry; a tool that will track nutrient management plans put into place. This tool could form a part of the future "evaluation tool box" for nutrient management plans in place in Ontario. The phasing in requirements of province-wide standards for nutrient management planning in Ontario and the eventual adoption over time of more sustainable farm practices should allow for ecosystem recovery with time.
The USDA's Natural Resources Conservation Service has

formed a team to revise its Nutrient Management Policy. The final policy was issued in the Federal Register in 1999. In December 2000, USDA published its Comprehensive Nutrient Management Planning Technical Guidance (CNMP Guidance) to identify management activities and conservation practices that will minimize the adverse impacts of animal feeding operations on water quality. The CNMP Guidance is a technical guidance document and does not establish regulatory requirements for local, tribal, State, or Federal programs. PNPs are complementary to and leverage the technical expertise of USDA with its CNMP Guidance. USEPA is proposing that Concentrated Animal Feeding Operations, covered by the effluent guideline, develop and implement a PNP. There is an increased availability of technical assistance for U.S. farmers via Technical Service Providers, who can provide assistance directly to producers and receive payment from them with funds from the Environmental Quality Incentives Program.

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Integrated Pest Management

Indicator # 7062

Assessment: Not Assessed

Purpose

- To assess the adoption of Integrated Pest Management (IPM) practices and the effects IPM has had toward preventing surface and groundwater contamination in the Great Lakes basin by measuring the acres of agricultural pest management applied to agricultural crops to reduce adverse impacts on plant growth, crop production and environmental resources.

Ecosystem Objective

A goal for agriculture is to become more sustainable through the adoption of more non-polluting, energy efficient technologies and best management practices for efficient and high quality food production. The sound use and management of soil, water, air, plant, and animal resources is needed to prevent degradation of agricultural resources. The process integrates natural resource, economic, and social considerations to meet private and public needs. This indicator supports Article V1 (e) - Pollution from Agriculture, as well as Annex 1, 2, 3, 11, 12 and 13 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Background

Pest Management is controlling organisms that cause damage or annoyance. Integrated pest management is utilizing environmentally sensitive prevention, avoidance, monitoring and suppression strategies to manage weeds, insects, diseases, animals and other organisms (including invasive and non-invasive species) that directly or indirectly cause damage or annoyance. Environmental risks of pest management must be evaluated for all resource concerns identified in the conservation planning process, including the negative impacts of pesticides in ground and surface water, on humans, and non-target plants and animals. The pest management component of an environmental conservation farm plan must be designed to minimize negative impacts of pest control on all identified resource concerns.

Agriculture accounts for approximately 35% of the land area of the Great Lakes basin and dominates the southern portion of the basin. Although field crops such as corn and soybeans comprise the most crop acreage, the basin also supports a wide diversity of specialty crops. The mild climate created by the Great Lakes allows for production of a variety of vegetable and fruit crops. These include tomatoes (for both the fresh and canning markets), cucumbers, onions and pumpkins. Orchard and tender fruit crops such as cherries, peaches and apples are economically important commodities in the region, along with grape production for juice or wine. The farmers growing these agricultural commodities are major users of pesticides.

Research has found that reliance on pesticides in agriculture is significant and that it would be impossible to abandon their use in the short term. Most consumers want to be able to purchase inexpensive yet wholesome food. Currently, other than organic production, there is no replacement system readily available at a reasonable price for consumers, and at a lesser cost to farmers, that can be brought to market without pesticides. Other research has shown that pesticide use continues to decline as measured by total active ingredient, with broad-spectrum pest control products being replaced by more target specific technology, and with lowered amounts of active ingredient used per acre. Reasons for these declines are cited as changing acreages of crops, adoption of integrated pest management (IPM) and alternative pest control strategies such as border sprays for migratory pests, mating disruption, alternative row spraying and pest monitoring.

With continued application of pesticides in the Great Lakes basin, non-point source pollution of nearshore wetlands and the effects on fish and wildlife still remains a concern. Unlike point sources of contamination, such as at the outlet of an effluent pipe, nonpoint sources are more difficult to define. An estimated 21 million kg of pesticides are used annually on agricultural crops in the Canadian and American Great Lakes watershed (GAO 1993). Herbicides account for about 75% of this usage. These pesticides are frequently transported via sediment, ground or surface water flow from agricultural land into the aquatic ecosystem. With mounting concerns and evidence of the effects of certain pesticides on wildlife and human health, it is crucial that we determine the occurrence and fate of agricultural pesticides in sediments, and in aquatic and terrestrial life found in the Great Lakes basin. Atrazine and metolachlor were measured in precipitation at nine sites in the Canadian Great Lakes basin in 1995 (OMOE 1995). Both were detected regularly at all nine sites monitored. The detection of some pesticides at sites where they were not used provides evidence of atmospheric transport of pesticides.

Cultural controls (such as crop rotation and sanitation of infested crop residues), biological controls, and plant selection and breeding for resistant crop cultivars have always been an integral part of agricultural IPM. Such practices were very important and widely used prior to the advent of synthetic organic pesticides. Indeed, many of these practices are still used today as components of pest management programs. However, the great success of modern pesticides has resulted in their use as the dominant pest control practice for the past several decades, especially since the 1950s. Newer pesticides are generally more water soluble, less strongly adsorbed to particulate matter, and less persistent in both the terrestrial and aquatic environments than the older contaminants, but they have still been found in precipitation at many sites.

Status of Integrated Pest Management

The Ontario Pesticides Education Program (OPEP) provides farmers with training and certification through a pesticide safety course. Figure 1 shows survey results for 5800 farmers who took pesticide certification courses over a three-year period (2001-2004). Three sustainable practices (alter spray practices/manage drift from spray, mix/load equipment in order to protect surface and/or groundwater, and follow label precautions) and the farmers' responses are shown. Results suggest that in 2004 more farmers "do or plan to do now" these three practices after being educated about their respective benefits. These practices have significant value for reducing the likelihood of impairing rural surface and groundwater quality. Figure 2 shows the acres of pest management practice applied to cropland in the U.S. Great Lakes basin for 2003.

Pressures

Pest management practices may be compromised by changing land use and development pressures (including higher taxes); flooding or seasonal drought; and lack of long-term financial incentives for adoption of environmentally friendly practices. In order for integrated pest management to be successful, pest managers must shift from practices focusing on purchased inputs (using commercial sources of soil nutrients (i.e. fertilizers) rather than manure) and broad-spectrum pesticides to those using targeted pesticides and knowledge about ecological processes. Future pest management will be more knowledge intensive and focus on more than the use of pesticides. Federal, provincial and state agencies, university Cooperative Extension programs, and grower organizations are important sources for pest management information and dissemination. Although governmental agencies are more likely to conduct the underlying research, there is significant need for private independent pest management consultants to provide technical assistance to the farmer.

Management Implications

All phases of agricultural pest management, from research to field implementation, are evolving from their current product-based orientation to one that is based on ecological principles and processes. Such pest management practices will rely more on an understanding of the biological interactions that occur within every crop environment and the knowledge of how to manage the cropping systems to the detriment of pests. The optimum results would include fewer purchased inputs (and therefore a more sustainable agriculture), as well as fewer of the human and environmental hazards posed by the broad-spectrum pesticides so widely used today. Although pesticides will continue to be a component of pest management, the following are sig-

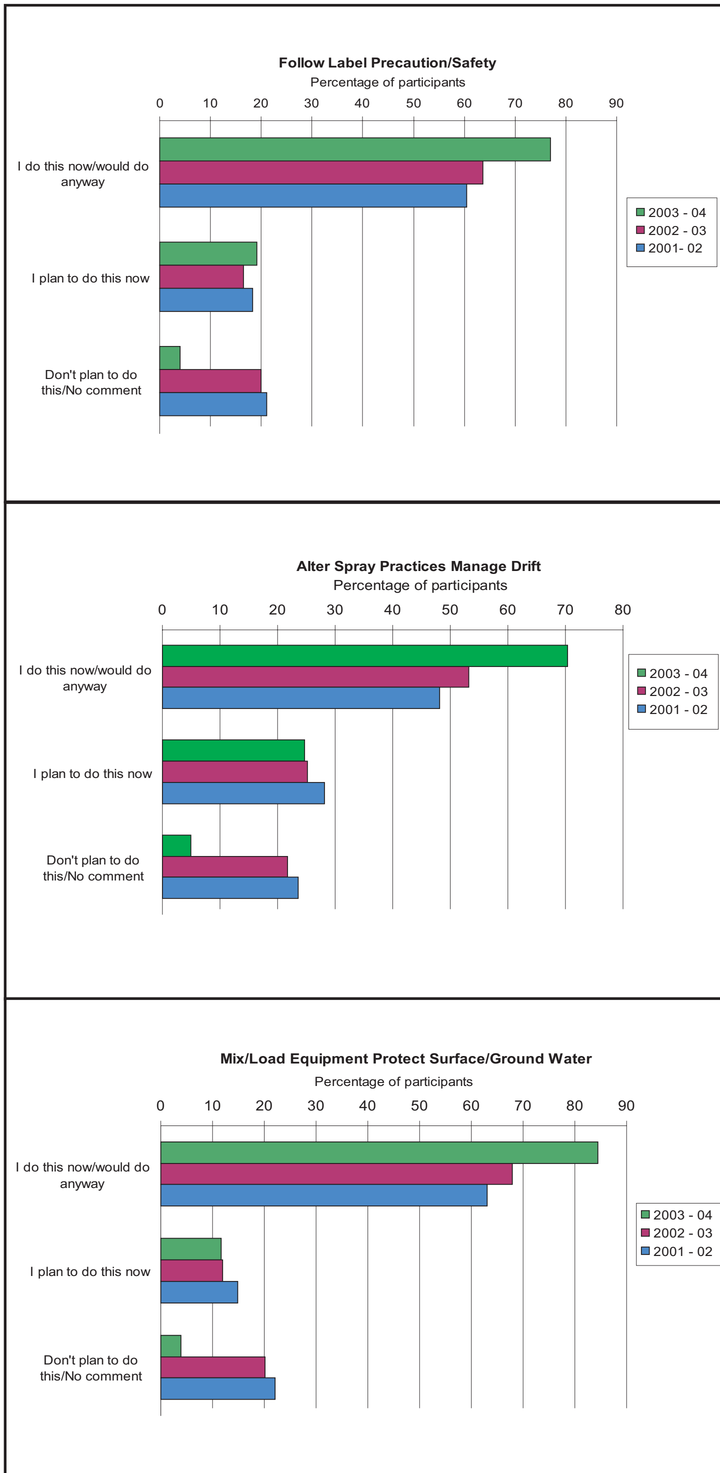

Figure 1. Ontario selected grower pesticide safety training course evaluation results from 2001-2004.
Source: Ontario Ministry of Agriculture and Food, Ontario Ministry of the Environment (OMOE) and the University of Guelph

nificant obstacles to the continued use of broad-spectrum pesticides: pest resistance to pesticides; fewer new pesticides; pesticide-induced pest problems; lack of effective pesticides; and human and environmental health concerns.

Based upon these issues facing pesticide use, it is necessary to start planning now in order to be less reliant on broad-spectrum pesticides in the future. Society is requiring that agriculture become more environmentally responsible through such things as the adoption of Integrated Pest Management. This will require effective evaluations of existing policies and implementing programs for areas such as Integrated Pest Management. To reflect these demands there is a need to further develop this indicator. The following types of future activities could assist with this process:

- Indicate and track future adoption trends of IPM best management practices;
- Analyze rural water quality data for levels of pesticide residues;
- Evaluate the success of the Ontario Pesticide Training Course, such as adding and evaluating survey questions regarding IPM principles and practices to course evaluation materials; and
- Evaluate the number of farmers and vendors who attended, were certified, or who failed the Ontario Pesticides Education Program.

Note: Grower pesticide certification is mandatory in Ontario and in all Great Lakes States, and it applies to individual farmers as well as custom applicators.

Acknowledgments
Authors: Peter Roberts, Water Quality Management Specialist, Resources Management, Ontario Ministry of Agriculture and Food, Guelph, peter.roberts@omaf.gov.on.ca;
Ruth Shaffer United States Department of Agriculture, Natural Resources Conservation Service, ruth.shaffer@mi.usda.gov; and Roger Nanney, Resource Conservationist, United States Department of Agriculture, Natural Resources Conservation Service.

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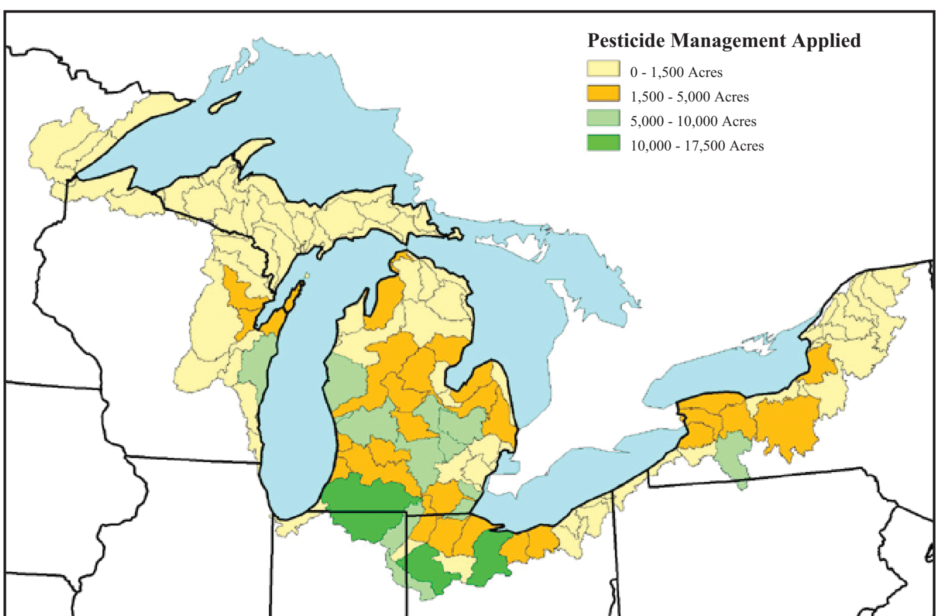

Figure 2. Annual U.S. Pesticide Management Systems Planned for 2003.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Performance and Results Measurement System

Vehicle Use
Indicator # 7064

Overall Assessment

Status:	**Poor**
Trend:	**Deteriorating**
Primary Factors Determining Status and Trend	**Population growth and urban sprawl in the Great Lakes Basin has led to an increase in the number of vehicles on roads, fuel consumption, and kilometers spent on the road by residents. Vehicle use is a driver of fossil fuel consumption, deteriorating road safety, and ecological impacts such as climate change and pollution.**

Purpose
To assess the amount and trends in vehicle use in the Great Lakes Basin (GLB) and to infer the societal response to the ecosystem stressed caused by vehicle use.

Ecosystem Objective
This indicator supports Annex 15 of the Great Lakes Water Quality Agreement. An alternative objective is to reduce stress on the environmental integrity of the Great Lakes region caused by vehicle use.

State of the Ecosystem
A suite of indicators monitoring vehicle use, the number of registered vehicles licensed, and fuel consumption is measured by governments in Canada and the United States to capture trends linked to fossil fuel consumption, deteriorating road safety, and ecological impacts such as climate change and pollution. Figure 1 shows the estimated total distance travelled by vehicles on roads in Ontario during 1993-2003 and the number of licensed vehicles registered in Ontario for the same period. The number of registered vehicles in Ontario rose 21% from over 6.3 million in 1990 to 7.6 million in 2004. More significant, however, is the estimated 122 million vehicle kilometers travelled (VKT) in Ontario, up 62% from 75 million in 1993. The greatest increase in VKT occurred between 1999 and 2000 (an increase of 39%). From this data, it is evident that Canadians in the Great Lakes Basin are increasingly spending more time on the road.

Looking to the U.S., Figure 2 shows the estimated trends in registered vehicles, licensed drivers, and vehicle kilometers travelled in the Great Lakes States from 1994 to 2004. The number of registered vehicles increased approximately 11% during this time period, while the number of licensed drivers only increased 8%. These increasing trends are somewhat lower than national averages in the U.S., showing increases of 20% and 13%, respectively. Just as in Ontario, VKT increased at a greater rate than the number of registered vehicles or licensed drivers. VKT increased in the Great Lakes States approximately 20% from 1994 to 2004, as compared to a 24% national U.S. increase. In 2004, U.S. residents in the Great Lakes States gained 7% more kilometres per vehicle than were driven in 1994.

A snapshot of the total registered vehicles in Ontario points abundantly to a societal dependence on private vehicles. Of the total registered vehicles in Ontario, passenger vehicles continually dominate road traffic, accounting for 74% of the total registered vehicles in 2004. As anyone who has driven on basin highways might guess, commercial freight traffic was the runner-up, accounting for 14% of road traffic in the same year. Notably, trucking flows of inter-provincial trade through Quebec and Ontario (both directions) also accounted for $41 billion worth of commodities or 30 per cent of total inter-provincial trade in Canada.

The movement of people is undoubtedly a driving force behind the economic profitability of the GLB. However, the tradeoffs of unsustainable modes of transport are evident. In Canada, road transportation, including private vehicles, represented 77% of total transportation in terms of energy use in 2004. As a result, energy-related GHGs rose by 25%, from 135.0 megatonnes to 168.8 megatonnes. In that same time period, the number of vehicles rose 8% faster than the number of people (Canada, 2005). In Ontario, sale of motor gasoline increased by 22% between 1989 and 2004 (Figure 3), on par with the national average. Gasoline sales rose from more than 12 billion litres to more than 15 billion litres between 1990 and 2003, with diesel fuel sales in Ontario alone doubling during the same period, from more than 12 million to almost 15 million litres. In the Great Lakes States, fuel (gasoline and gasohol) consumption for vehicles increased by 17% from 1994 to 2004, as compared to a 24% increase nationally in the U.S. It is noteworthy to point out that use of ethanol blended fuels (gasohol) in the Great Lakes States increased 160% over this time period. Gasohol now comprised approximately 39% of fuel consumption in the Great Lakes States. The increased demand for fuel in both countries is driven by a rise in number of vehicles on highways, increased power of automobile engines, and the growing popularity of sports utility vehicles and large-engine cars (Ménard, 2006)

Over the last decade, consumers have also shown a strong preference for high-performance vehicles. Since 1999, the production of Sport Utility Vehicles (SUVs) has dominated the automotive industry, surpassing the output of both minivans and pickup trucks nation wide. For the period of January to September 2004, SUVs accounted for 18% of total light-duty vehicle manufacturing, which assembles passenger cars, vans, minivans, pickup trucks and SUVs in Canada (Magnusson, 2005). In the Great Lakes States, the registrations of private and commercially owned trucks, which include personal passenger vans, passenger minivans, and sport-utility vehicles, have increased approximately 50% from 1994 to 2004. Private and commercially owned trucks now comprise about 37% of all registered vehicles in the Great Lakes States. Although the fuel economy of the average new car has improved more than 76% since 1975, the automotive industry has traded off fuel consumption improvements in new vehicles for more powerful engines. This improved performance reduced the fuel economy that otherwise could have been achieved, meaning, cars collectively get worse gas mileage today than they did in the mid-1980's (NRC, 1992)—the effects of which are experienced with diminished air quality locally.

Pressures

Suburban development has become the predominant form of growth in the Great Lakes Basin. The mixed assessment in the GLB urban air quality can be directly linked to the increase in traffic congestion. Presently, transportation GHG emissions are increasing at a slower rate than activity because of the more efficient travel of people and goods. However, all modes of transport are still greatly dependent on GHG-intensive hydrocarbons to provide them with energy. As a major driver of ecological stress, vehicles are the single largest domestic source of the smog-causing greenhouse gas (GHG) emissions. These emissions include nitrogen oxides (NOx) and volatile organic compounds (VOCs) as well as carbon monoxide (CO), all which contribute contaminants to air and water systems (MOE, 2005). Such pollutants have been connected with respiratory problems and premature death. There is strong evidence that atmospheric deposition is a source of pollutants in storm water runoff, and that this runoff reaches streams, rivers and other aquatic resources (IJC, 2004). Congestion caused by automobiles and vehicle-related development also degrades the liveability of urban environments by contributing noise, pollution, and fatalities. Positive trends in road use may also lead to further fragmentation of natural areas in the basin.

Management Implications

There is a need to reduce the volume and congestion of traffic in the GLB. While progress has been made through less polluting fuels and emission reduction technologies, and economic tools such as the tax incentives that encourage the purchase of fuel-efficient vehicles (e.g. Tax for Fuel Conservation), issues of urban sprawl must also be managed. Recent studies by the U.S. EPA found that infill development and re-development of older suburbs could reduce VKT per capita by 39% to 52% (depending on the metropolitan area studied) (Chiotti, 2004). The success of current strategies will assist managers and municipalities protect natural areas, conserve valuable resources (such as agriculture and fossil fuels), ensure the stability of ecosystem services, and prevent pollution. Under the Kyoto Protocol, Canada is committed to reducing its GHG emissions by 6% below 1990 levels by the year 2010, even though the government may consider new targets.

Over the next 30 years, the number of people living in Ontario is expected to grow by approximately four million, the majority of which are expected to reside in the GLB. In the Golden Horseshoe Area alone, 2031 forecasts predict that the population of this area is to grow by an additional 3.7 million (from 2001) to 11.5 million. The McGuinty government has invested in the several initiatives (including, Bill 26, the Strong Communities Act, 2004) in order to manage regional growth and development, and municipalities and regions within the GLB are developing their own plans within the common mandate.

Improving public transit is the first investment priority, however there is an acknowledgment that improving population growth forecasts, intensifying land use, revitalizing urban spaces, diversifying employment opportunities, curbing sprawl, protecting rural areas, and improving infrastructure are all part of the solution. Urban development strategies must be supported by positive policy and financial frameworks that allow municipalities to remain profitable, while creating affordable housing and encouraging higher density growth in the right locations. Further research, investment and action are needed to explore multi-modal corridors and modes for transporting goods in the basin.

Comments from the author(s)

It should be noted that Canadian Vehicle Kilometres Travelled (VKM) data is based on a voluntary vehicle-based survey conducted by Transport Canada. The measure of vehicle-kilometres travelled does not take into account occupancy rates, which affect the sustainability of travel.

It also should be noted that U.S. motor fuel data come from the records of State agencies that administer the State taxes on motor fuel are the underlying source for most of the data presented in these tables. Over the last several years, there have been numerous changes in State fuel tax laws and procedures that have resulted in improved fuel tax compliance, especially for diesel fuel.

The improved compliance has resulted in increased fuel volumes being reported by the States to FHWA. The trends shown in the tables reflect both improvements in tax compliance and changes in consumption.

U.S. VKT data - These data are derived from the Highway Performance Monitoring System (HPMS). The HPMS is a combination of sample data on the condition, use, performance and physical characteristics of facilities functionally classified as arterials and collectors (except rural minor collectors) and system level data for all public roads within each State.

Although data about VKT, registered vehicles, and fuel consumption was only available up to 2004, the authors feel this indicator should be updated in future to examine potential shifts in vehicle-use behaviours based on the recent rise in gasoline prices, which began climbing in late 2002. A 2005 report by Transport Canada, based on partial data, suggest that gas prices post-Hurricane Katrina had an impact on fuel consumption nationally.

Acknowledgments
Authors: Katherine Balpataky, Environment Canada, Burlington; and Todd Nettesheim, U.S. EPA, Great Lakes National Program Office, Chicago, IL.

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Table 1: Primary energy consumption of Motor Gasoline and Diesel Fuel, Canada, 1990 and 2003.
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Figure 3. Petroleum Consumption in Ontario.
Data source: Statistics Canada's Energy Statistics Handbook. 2006

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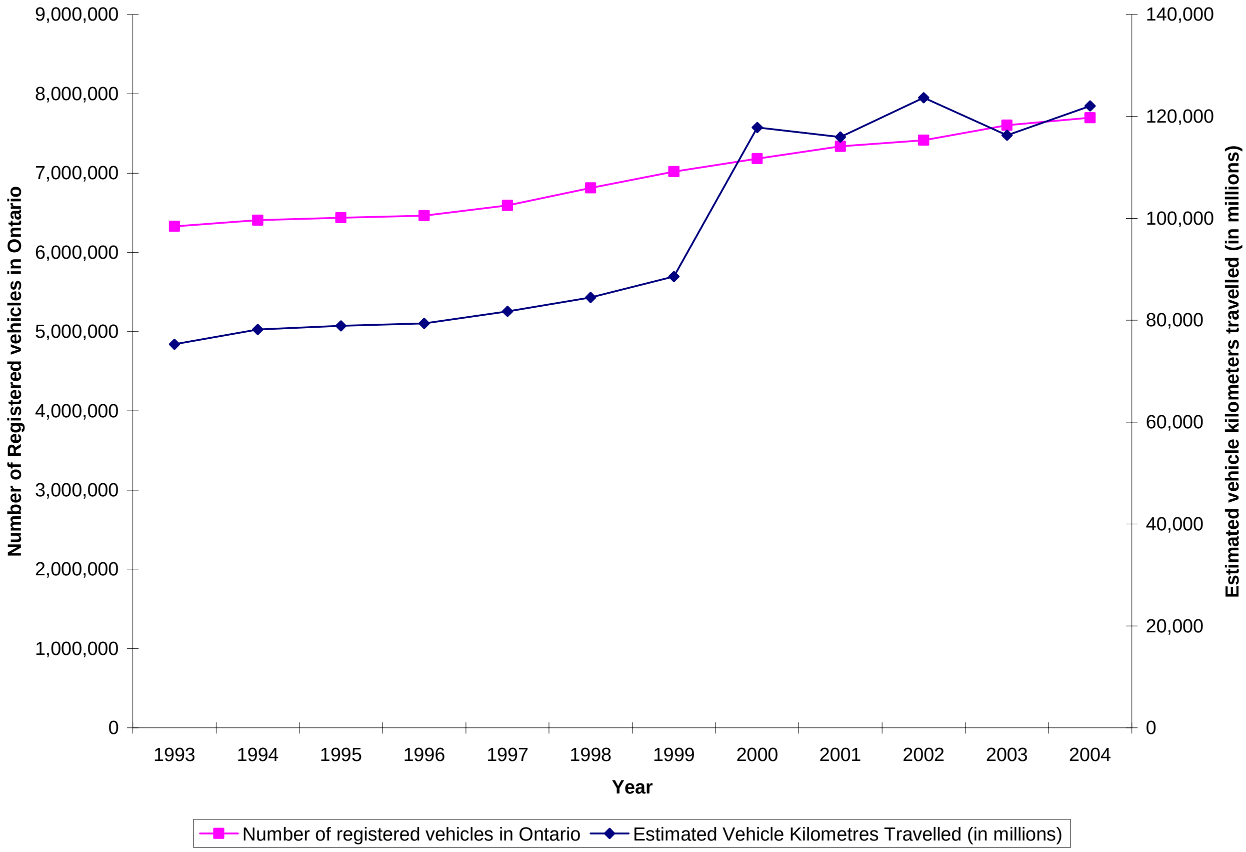
Variable	Level		Variation from 1990 to 2003		% share of energy consumed		% contribution to change
	1990	2003	value	%	1990	2003	
Primary energy consumption in terajoules							
Motor gasoline	432,446	539,230	106,784	25	15	16	22
Diesel fuel	169,466	248,437	78,971	47	6	8	16

Table 1. Primary energy consumption of Motor Gasoline and Diesel Fuel, Canada, 1990 and 2003.
Source: Report on energy supply-demand in Canada, Statistics Canada Catalogue No. 57-003-XIB, 1990 and 2003; population estimates, CANSIM Table 051-0001; Real GDP, CANSIM Table 384-0013.



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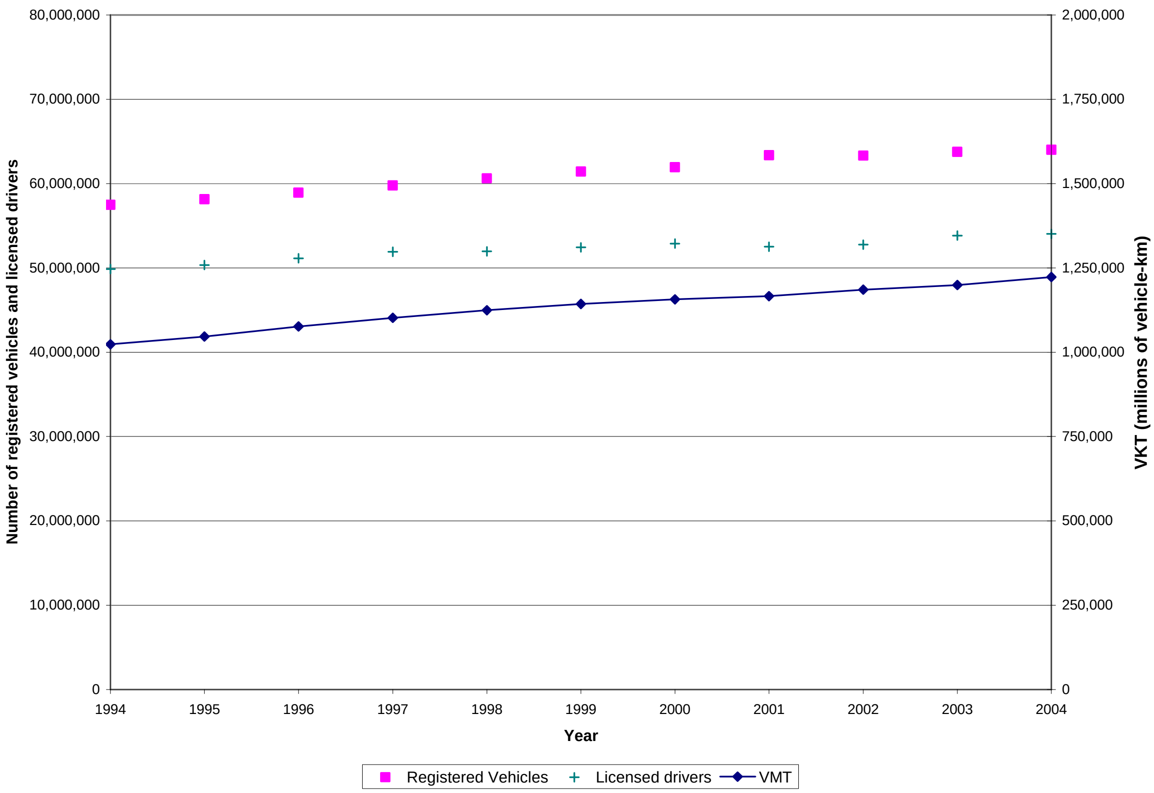

Figure 2. Number of Registered Vehicles, Licensed Drivers and Vehicle Kilometres Travelled in Great Lakes States.
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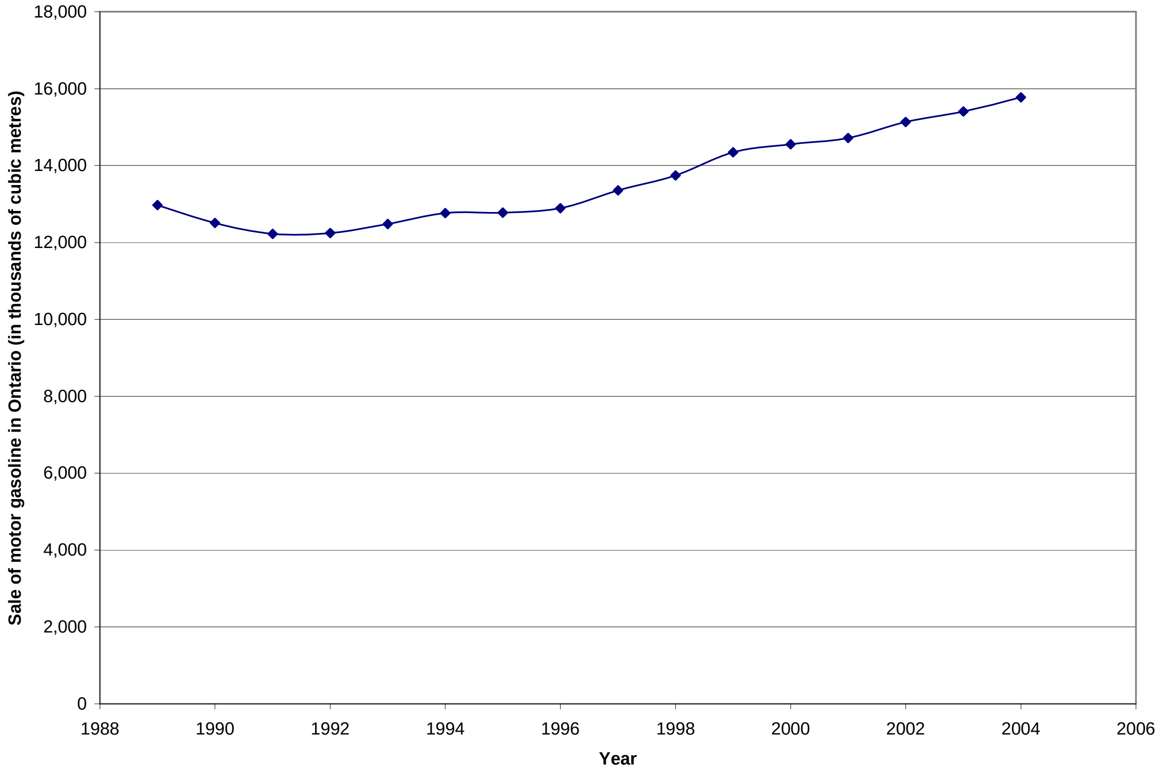

Figure 3. Petroleum Consumption in Ontario.
Data source: Statistics Canada's Energy Statistics Handbook. 2006

Wastewater Treatment and Pollution
Indicator # 7065

Note: This is a progress report towards implementation of this indicator.

Overall Assessment

Status:	**Not Assessed**
Trend:	**Undetermined**
Primary Factors Determining Status and Trend	**Data to support this indicator have not been summarized according to quality control standards. Compilation of a comprehensive report on wastewater treatment and pollution in the Great Lakes will require a substantial amount of additional time and effort.**

Lake-by-Lake Assessment
A lake-by-lake assessment is not available at this time as data summarization is incomplete and not available for analysis on a lake-by-lake basis.

Purpose *(proposed)*
- To measure the proportion of the population served by municipal sewage treatment facilities
- To evaluate the level of municipal treatment provided
- To measure the percent of collected wastewater that is treated; and
- To assess the loadings of metals, phosphorus, Biochemical Oxygen Demand (BOD), and organic chemicals released by wastewater treatment plants into the water courses of the Great Lakes basin.

Ecosystem Objective
The purpose of this indicator is to assess (1) the reduction of pressures induced on the ecosystem by insufficient wastewater treatment networks and procedures and (2) to further the progression of wastewater treatment towards sustainable development.

This indicator is also intended to (3) assess the scope of municipal sewage treatment and the commitment to protecting freshwater quality in the Great Lakes basin. The quality of wastewater treatment determines the potential adverse impacts to human and ecosystem health as a result of the loadings of pollutants discharged into the Great Lakes basin.

State of the Ecosystem
<u>Background Information</u>
Wastewater refers to the contents of sewage systems drawing liquid wastes from a variety of sources, including municipal, institutional and industrial, and stormwater discharges. After treatment, wastewater is released into the environment from a treatment plant as effluent into receiving waters such as lakes, ponds, rivers, streams and estuaries.

Wastewater contains a large number of potentially harmful pollutants, including some that are the result of biological activity as well as others that are part of the over 200 identified chemicals from industries, institutions, households, and other sources. Wastewater systems are designed to collect and treat these wastes using various levels of treatment to remove pollutants prior to discharge, ranging from no treatment to very sophisticated and thorough treatments. Despite treatment, effluents released from wastewater systems can still contain pollutants of concern, since even advanced treatment systems do not necessarily remove all pollutants and chemicals.

The following constituents, mostly associated with human waste, are present in all sewage effluent to some degree:

- biodegradable oxygen-consuming organic matter (measured as biochemical oxygen demand or BOD);
- suspended solids (measured as total suspended solids or TSS);
- nutrients, such as phosphorus (usually measured as total phosphorus) and nitrogen-based compounds (nitrate, nitrite, ammonia, and ammonium, which are measured either separately or in combination as total nitrogen);
- microorganisms (which are usually measured in terms of the quantity of representative groups of bacteria, such as fecal coliforms or fecal streptococci, found in human wastes);
- sulphides;
- assorted heavy metals; and
- trace amounts of other toxins and emerging chemicals of concern that have yet to be consistently monitored for in wastewater effluents.

Municipal Wastewater Effluent (MWWE) is one of the largest sources of pollution, by volume, discharged to surface water bodies in Canada (CCME, 2006). Reducing the discharge of pollution through MWWE requires a number of interventions ranging from source control to end of pipe measures.

<u>Levels of Treatment in the U.S. and Canada</u>

The concentration and type of effluent released into the receiving body of water depends heavily on the type of sewage treatment used. As a result, information regarding the level of treatment that was used on wastewater is integral in assessments of potential impacts on water quality. In both the United States and Canada, the main levels of wastewater treatment used include primary, secondary, and advanced or tertiary.

In primary wastewater treatment, solids are removed from raw sewage primarily through processes involving sedimentation. This process typically removes roughly 25-35% of solids and related organic matter (U.S. EPA 2000).

In the U.S., pretreatment may also occur preliminary to primary treatment, in which contaminants are reduced and large debris is removed from industrial wastewater before it is discharged to municipal treatment systems to undergo regular treatment. U.S. federal regulations require that Publicly Owned Treatment Works (POTW) Pretreatment Programs include the development of local pretreatment limits in situations where industrial pollutants could potentially interfere with municipal treatment facility operations or contaminate sewage sludge. The U.S. EPA can authorize the states to implement their own Pretreatment Programs as well. Of the eight states that are part of the Great Lakes basin, Michigan, Minnesota, Ohio and Wisconsin currently hold an approved State Pretreatment Program, (U.S. EPA, NPDES 2006).

Secondary wastewater treatment includes an additional biological component in which oxygen-demanding organic materials are removed through bacterial synthesis enhanced with oxygen injections. About 85% of organic matter in sewage is removed through this process, after which the excess bacteria are removed, (U.S. EPA 1998). Effluent can then be disinfected with chlorine prior to discharge in an effort to kill potentially harmful bacteria. Subsequent dechlorination is also often required to remove excess chlorine that may be harmful to aquatic life.

Secondary treatment effluent standards are established by the EPA and have technology-based requirements for all direct discharging facilities. These standards are expressed as a minimum level of effluent quality in terms of biochemical oxygen demand measurements over a five-day interval (BOD5), total suspended solids (TSS) and pH. Secondary treatment of municipal wastewater is the minimum acceptable level of treatment according to U.S. federal law unless special considerations dictate otherwise (U.S. EPA 2000).

Advanced, or tertiary, levels of treatment often occur as well and are capable of producing high-quality water. Tertiary treatment can include the removal of nutrients such as phosphorus and nitrogen and essentially all suspended and organic matter from wastewater through combinations of physical and chemical processes. Additional pollutants can also be removed when processes are tailored for those purposes.

Data on the level of treatment utilized in the United States are available from the Clean Water Needs Survey (CWNS). This cooperative effort between the U.S. EPA and the states resulted in the creation and maintenance of a database with technical and cost information on the 16,000 publicly owned wastewater treatment facilities in the nation. According to the results of the 2000 CWNS, the total population served by POTWs in the U.S. portion of the Great Lakes basin was 17,400,897 in 2000. Of this number, 0.7% received treatment from facilities that do not discharge directly into Great Lakes waterways and dispose of wastes by other means, 14.1% received secondary treatment, and 85.3% received treatment that was greater than secondary, making advanced treatment the type used most extensively. Please see Figure 1 for the complete distribution of population served according to level of treatment by major lake and river basins within the U.S. Great Lakes watershed. These values do not include a possible additional 12,730 people who were reportedly served by facilities in New York for which watershed locations are unknown within the CWNS database. Although the facilities are in counties at least partially within the U.S. portion of the Great Lakes region, their location within Great Lakes watersheds can not be easily verified.

Wastewater Treatment Plants (WTPs) in Ontario also use primary, secondary, and tertiary treatment types. The processes are very similar, if not the same to those used in the U.S. (described above), but Canadian regulatory emphasis is placed on individual effluent quality guidelines as opposed to mandating that a specific treatment type be utilized across the province.

A complete distribution of population served according to level of treatment is not available in the Great Lakes basin for Ontario at this time. However, for a general understanding, a distribution of the population served by each treatment type for all of Canada is available in Figure 2.

Tertiary or advanced treatment is the most common type of sewage treatment across the basin, which can be inferred from the combined trends demonstrated in both Figures 1 and 2. This indicates the potential for high effluent water quality, which can only be verified through analysis of regulatory and monitoring programs.

Condition of Wastewater Effluent in Canada and the United States:
Regulation, Monitoring, and Reporting

Canada does not regulate effluent conditions through treatment level requirements, but instead sets specific limits for each individual WTP, no matter which type of treatment is used. In the U.S., effluent limits are standardized by the Federal Government, but the states have the power to make alterations as long as minimum guidelines are met.

Each federally managed wastewater treatment plant (WTP) in Canada must also follow guidelines given by the Federal Government. Effluent guidelines for wastewater from Federal facilities are to be equal to or more stringent than the established standards or requirements of any Federal or Provincial regulatory agency (Environment Canada, 2004). The guidelines indicate the degree of treatment and the effluent quality applicable to the wastewater discharged from the specific WTP. Use of the Federal guidelines is intended to promote a consistent wastewater approach towards the cleanup and prevention of water pollution and ensure that the best practicable control technologies are used (Environment Canada, 2004).

Table 1 lists the pollutant effluent limits specified for all federally approved WTPs in Ontario. The effluents discharged to the receiving water should receive treatment such that an effluent of minimum quality is achieved. In general, compliance with the numerical limits should be based on 24 hour composite samples (Environment Canada, 2004).

In Ontario, wastewater treatment and effluents are monitored through a Municipal Water Use Database (MUD) through Environment Canada. This database uses a survey for all municipalities to report on wastewater treatment techniques. Unfortunately, the last complete survey is from 1999 and this data are not sufficient to use for this report. The most up to date municipal water use survey will be released within the next few months and would useful to examine the treatment results within Canada. Unfortunately, the survey is not yet available, and other methods have been chosen to examine wastewater treatment in Ontario, which are explained in the *Attempted Eperimental Protocols* section of this progress report.

The U.S. regulates and monitors wastewater treatment systems and effluents through a variety of national programs. The U.S. EPA's Office of Wastewater Management promotes compliance with the Clean Water Act through the National Pollutant Discharge Elimination System (NPDES) Permit Program. These permits regulate wastewater discharges from POTWs by setting effluent limits, monitoring and reporting requirements, and they can lead to enforcement actions when excessive violations occur. The U.S. EPA can authorize the states to implement all or part of the NPDES program, and all US states in the Great Lakes region are currently approved to do so provided they meet minimum federal requirements, (U.S. EPA, NPDES 2006). This distribution of implementation power can create difficulties when specific assessments are attempted across regions spanning several states.

Large scale national assessments of wastewater treatment have been completed in the past by using BOD and dissolved oxygen (DO) levels as indicators of water quality. Since DO levels have been proved to be related to BOD output from wastewater discharges (increased BOD loadings lead to greater depletion of oxygen and lower DO levels in the water), historical DO records can be a useful indicator of water quality responses to wastewater loadings. According to a national assessment of wastewater treatment completed in 2000, the U.S. Great Lakes basin had a statistically significant improvement in worst-case DO levels after the Clean Water act (U.S. EPA 2000). The study's design estimates also showed that the national discharge of BOD_5 in POTW effluent decreased by about 45%, despite a significant increase of 35% in the population served and the influent loadings. This improving general trend supported assumptions made in the 1996 CWNS Report to Congress that the efficiency of BOD removal would increase due to the growing proportion of POTWs using advanced treatment processes across the nation.

Although specific case studies do exist, unfortunately comprehensive studies such as the examples listed above have not been conducted for pollutants other than BODs, and have not been completed to an in-depth level for the Great Lakes region.

An extensive investigation of the Permit Compliance System (PCS) database is one way such a goal can be accomplished. This national information management system tracks NPDES data including permit issuance, limits, self-monitoring, and compliance. The PCS database can provide the information necessary to calculate the loadings of specific chemicals present in wastewater effluent from certain POTWs in the U.S. portion of the Great Lakes basin, providing the relevant permits exist.

Attempted Experimental Protocol for Calculating Pollutant Loadings from Wastewater Treatment Plants to the Great Lakes

This calculation was attempted for the U.S. and Canadian portion of the G.L. basin during the compilation of this report, and although an extensive amount of data are available and have been retrieved, their summarization to an appropriate level of quality control is substantially difficult and is not complete at this time. The protocol followed thus far is outlined below.

The initial procedure for mining the U.S. data from the PCS database began with the compilation of a list of all the municipal wastewater treatment facilities located within the Great Lakes basin. The determination of which pollutants were most consistently permitted for across the basin followed, and the effluent loadings data for all facilities that monitored for those parameters were obtained for 2000 and 2005. These pollutant parameters were often referred to by various common names in the database, which additionally complicated extraction of concise data. The resulting mass of data was extremely large and could not be feasibly summarized due to internal inconsistencies such as difference in units of measurement, monitoring time frames, extreme outliers, and apparent data entry mistakes.

In an effort to decrease the amount of U.S. data requiring analysis at a more precise level, (as a result of the problems mentioned above,) several specific facilities throughout the basin were chosen to hopefully serve as representative case studies off which total loadings estimates could be calculated. These facilities were chosen by two sets of criteria. The first was according to location within the basin, to ensure that all states and each Great Lake were represented. The second criteria was the greatest average level of effluent flow, as the selected facilities could potentially have the greatest impact due to sheer volume of effluent, and these values could also be used to calculate loadings in cases where pollutant measurements were gathered as a concentration as opposed to by quantity (as was often the case). Fifteen facilities were eventually selected for further analysis, and corresponding effluent measurements for basic pollutants were extracted from the PCS database. Calculation of percent change in pollutant loadings and the number of violations from 2000 to 2005 was attempted for these data, but results are not available yet due to the data quality issues described earlier.

With total effluent loadings being so difficult to calculate independently from database records, government generated historical records of effluent limit violations can provide some insight into the performance of U.S. Great Lakes wastewater treatment facilities. The Enforcement and Compliance History Online (ECHO) is a publicly accessible data system funded by the EPA that was used to obtain violation information by quarter over a three year time span for the group of 15 U.S. facilities previously selected for loadings calculations.

The resulting compliance data are presented in Figure 3 according to each pollutant for which violations of permitted effluent levels occurred during the 12 possible quarters under investigation from 2003-2006. This information is further separated out into quarters that demonstrated basic violations of effluent limits and those that had a significant level of non-compliance with permitted effluent limits. Chloride, fecal coliform, and solids violations were the most common, with copper, cyanide, and mercury having higher numbers of violations as well. Chloride, copper, mercury, and solids violations showed the most significant non-compliance with permitted levels.

In Ontario, wastewater treatment plants must report on the operation of the system and the quality of the wastewater treatment procedures on an annual basis to satisfy the requirements of the Ontario Ministry of Environment and the Certificate of Approval. Each report fulfills the reporting requirements established in section 10(6) of the Certificate of Approval made under the *Ontario Water Resources Act* (R.S.O. 1990, c. O.40). As a result of these requirements, effluent limit violations for BOD, phosphorus, and suspended solids should be available for future analysis. Data are too extensive to summarize at this time to a sufficient level of quality control.

Since results from the Municipal Water Use Database were not available at this time, the data used for the Canadian component of this report were provided by 10 municipalities in the Great Lakes basin. Municipalities were randomly chosen based on their proximity to the great lakes and their population of over 10,000. Most of the chosen municipalities had about one to three wastewater treatment plants, which compiled to 24 treatment plants being examined in total for this indicator report. Data from 2005 annual reports for each wastewater treatment plant were used to analyze wastewater treatment procedures and associated effluent quality for this indicator, with special focus on four specific pollutant parameters. These include BOD, phosphorus and suspended solids, all of which are indicators of potential health hazards.

These parameters are regulated by most wastewater treatment plants, which when exceeded, have the potential to have serious effects on human health. Current targets exist to minimize environmental and health impacts. For example, Ontario WTPs have a target of 50% for the removal of BOD and limits must not exceed 20mg/L in a 5 day span. The target for the removal of suspended solids is 70%, with a limit of 25 mg/L in a 24 hour sample period. And although some nutrients are essential for plant production in all aquatic ecosystems, an oversupply of nutrients, particularly from municipal wastewater effluents, can lead to the growth of large algal blooms and extensive weed beds (Environment Canada 2001). Resulting wastewater effluent limits for phosphorus in Ontario have been set at 1.0mg/L accordingly. Completed results corresponding to the exceedences of these limits are not available for Ontario at this time.

Pressures
There are numerous challenges to providing adequate levels of wastewater treatment in the Great Lakes basin. These include: facility aging, disrepair and outdatedness; population growth that stresses the capabilities of existing plants and requires the need for more facilities; new and emerging contaminants that are more complex and prolific than in the past; and new development that is located away from urban areas and served by decentralized systems (such as septic systems) that are much harder to regulate and monitor. The escalating costs associated with addressing these challenges continue to be a problem for both U.S. and Canadian municipalities, (U.S. EPA, 2004 and Government of Canada, 2002).

Management Implications
Despite demonstrated significant progress with wastewater treatment across the basin, substantial problems remain with regards to nutrient enrichment, sediment contamination, heavy metals, and toxic organic chemicals that still pose threats to the environment and human health. It is therefore important to continually invest in wastewater treatment infrastructure improvements, so any current achievements in water pollution control are not overwhelmed by the demands of future urban population growth and so other remaining concerns can be addressed such as polluted urban runoff and untreated municipal stormwater. These sources have emerged as prime contributors to local water quality problems throughout the basin (Environment Canada, 2004). WTPs are having difficulties keeping up with demands created by urban development which cause an increasing amount of bypass into the Great Lakes. The governments of Canada and Ontario and municipal authorities, working under the auspices of the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA), have been developing and evaluating new stormwater control technologies and sewage treatment techniques to resolve water quality problems (Environment Canada, 2004). Under the new COA, Canada and Ontario will continue to build on this work, implementing efficient and cost effective projects to reduce the environmental damage of a rapidly expanding urban population (Environment Canada, 2004).

Municipal wastewater effluent (MWWE) is currently managed through a variety of policies, by-laws and legislation at the federal, provincial/territorial and municipal levels (CCME, 2006). This current variety of policies unfortunately creates confusion and complex situations for regulators, system owners and operators. As a result, the Canadian Council of Ministers of the Environment (CCME) has established a Development Committee to develop a Canada-wide Strategy for the management of MWWE by November 2006. An integral part of the strategy's development will be to consult with a wide variety of stakeholders to ensure that management strategies for MWWE incorporate their interests, expertise and vision. The strategy will address a number of governance and technical issues, resulting in a harmonized management approach (CCME, 2006).

The presence of emerging chemicals of concern in wastewater effluent is another developing issue that requires attention. Current U.S. State and municipality permit requirements are based on state water quality laws that are developed according to pollutants anticipated to exist in the community. This is also true for the WTP in Ontario. This means the existence of new potentially toxic substances can be overlooked. So even in areas with a high degree of municipal wastewater treatment, pollutants such as endocrine-disrupting substances can inadvertently pass through wastewater treatment systems and into the environment. These substances are known to disrupt or mimic naturally occurring hormones and may have an impact on the growth, reproduction, and development of many species of wildlife. Additional monitoring for these pollutants and corresponding protection and regulation measures need to be investigated and implemented.

The methodologies used in the U.S. national assessments of wastewater treatment could potentially be reproduced and used to detect loadings trends and performance measures for additional pollutants in the Great Lakes. The QA/QC safeguards included in such methods could lead to very useful analyses of watershed-based point source controls. Sufficient resources in terms of time and funding need to be allocated in order to accomplish this task.

Comments from the author(s)
The actual proportion of the entire population receiving treatment can not be calculated until a definite population for the Great Lakes basin can be obtained for the same time period. Several different population estimates exist for the region, but they were compiled according to county in the U.S., and therefore represent a skewed total for the population that actually resides within the boundaries of the Great Lakes watershed. GIS analysis of census data needs to be completed in order to obtain a more accurate value for the Great Lakes population.

In Canada, only one year was assessed due to lack of available data. In future years, data from the Environment Canada MWWS survey would be useful to use, but the survey is currently only updated to 1999, which unfotunately would not be useful for this report. The newest survey will be out within the next year and it should be examined in future assessments for this indicator.

Several problems exist in the calculation of effluent loadings. For example, actual flow through effluent is not consistently monitored for in the U.S. Although influent levels are obtainable for every facility, there is no way to ensure that the effluent is comparable, since a substantial volume may be removed during treatment processes. Since effluent flow is sometimes necessary to calculate loadings from concentration values of pollutants, precise estimates of total loadings to Great Lakes waters may be next to impossible to obtain on a large scale.

Another future effort towards the implementation of this indicator would be to use a consistent guideline when analyzing wastewater treatment in both the U.S. and Canada. In the U.S. portion of the basin, data were compiled from several different databases, with population information derived from a separate source than effluent monitoring reports. For Ontario, data from randomly chosen municipalities serving a population of 10,000 or greater were available for analysis. Focusing on this criterion for wastewater treatment can only provide a fragmented view of the treatment patterns in the Canadian Great Lakes basin; however, by using a consistent wastewater treatment analysis guideline, bias results would be avoided.

Furthermore, a more organized monitoring program must be implemented in order to successfully correlate wastewater treatment quality with the status of the Great Lakes basin. Although the wastewater treatment plants provide useful monitoring information regarding the quality of wastewater, they only state the quality of that specific municipality, rather than the overall quality of the great lakes. Implementation of a more standardized, updated approach to monitoring contaminants in effluent and reporting data for wastewater treatment is needed to address this issue. Additionally, the difference in monitoring requirements between Canada and the U.S. make it difficult to assess the quality of wastewater treatment on a basin-wide scale. A standardized reporting format and inclusive database, accessible to all municipalities, researchers, and the general public, should be established for binational use. This would make trend analysis easier, and thus provide a more effective assessment of the potential health hazards associated with wastewater treatment for the Great Lakes as a whole.

Considering all the difficulties encountered while attempting to adequately summarize the vast amount of U.S. effluent monitoring data contained in the PCS database, the logical solution would be to request an application that could automate accurate calculations. Interestingly, such an application previously existed that was capable of producing effluent data mass loadings reports from the PCS database, but it was discontinued due to the modernization of the PCS system that is currently underway. While the PCS system is being updated, adequate resources have not been available to extend this overhaul to the previously mentioned application as of yet, and the lack of substantial use of the application in the past raised concern over its cost-effectiveness. Additionally, incorporating this component into the current modernization could take years due to various logistical problems, including the inherent quality assurance controls needed for PCS metadata before potential loadings results could be accepted as reliable, high quality data (personal communication with James Coleman, 2006).Despite these problems, the reinstatement of such a tool would solve the data summarization needs presented in this indicator report and could lead to an effective, comprehensive, and time-efficient analysis of pollutant loadings to the Great Lakes from wastewater treatment plants.

Acknowledgments
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* Lake St. Clair and Detroit River watersheds are also considered part of the Lake Erie basin
** MI Unknown refers to the population served by facilities in the state of Michigan for which exact watershed locations are unknown, so the data could not be grouped with a specific lake basin. Population could potentially be distributed between the Lakes Michigan, Huron, or Erie.
Source: 2000 Clean Watershed Needs Survey

Figure 2. Percent of Population Served in Canada by Each Treatment Type in 1999.
Source: Municipal Water Use Database Web site:
(http://www.ec.gc.ca/water/en/manage/use/e_data.htm)

Figure 3. Total number of quarters with reported effluent limit violations by pollutant for selected U.S. facilities
Caption: Data was compiled from 15 different facilities according to the total number of quarters that were in non-compliance of at least one pollutant effluent limit permit during 2003-2006.
* = combination of violations for 5-day BOD listed as total % removal and total
** = combination of violations for fecal coliform listed as general and broth totals
*** = combination of violations for cyanide listed as A and CN totals
**** = combination of violations for total nitrogen listed as N and as NH3
***** = combination of violations for solids as listed as total settleable, total dissolved, total suspended, and suspended % removal

Source: U.S. EPA. "Enforcement & Compliance History Online (ECHO)." *Compliance and Enforcement.* September 2006. U.S. EPA, Office of Enforcement and Compliance Assurance. http://www.epa.gov/echo/index.html (Accessed September27, 2006).

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Pollutant Effluent	Limit
5 day Biochem Biochemical Oxygen Demand	20 mg/L
Suspended Solids	25 mg/L
Fecal Coliforms	400 per 100 mL (after disinfection)
Chlorine Residual	0. 50 mg/L minimum after 30 minutes contact time
pH	6 to 9
Phenols	20 micrograms/L
Oils & Greases	15 mg/L
Phosphorus (Total P)	1 .0 mg/L
Temperature	Not to alter the ambient water temperature by more than one degree Centigrade (1ºC).

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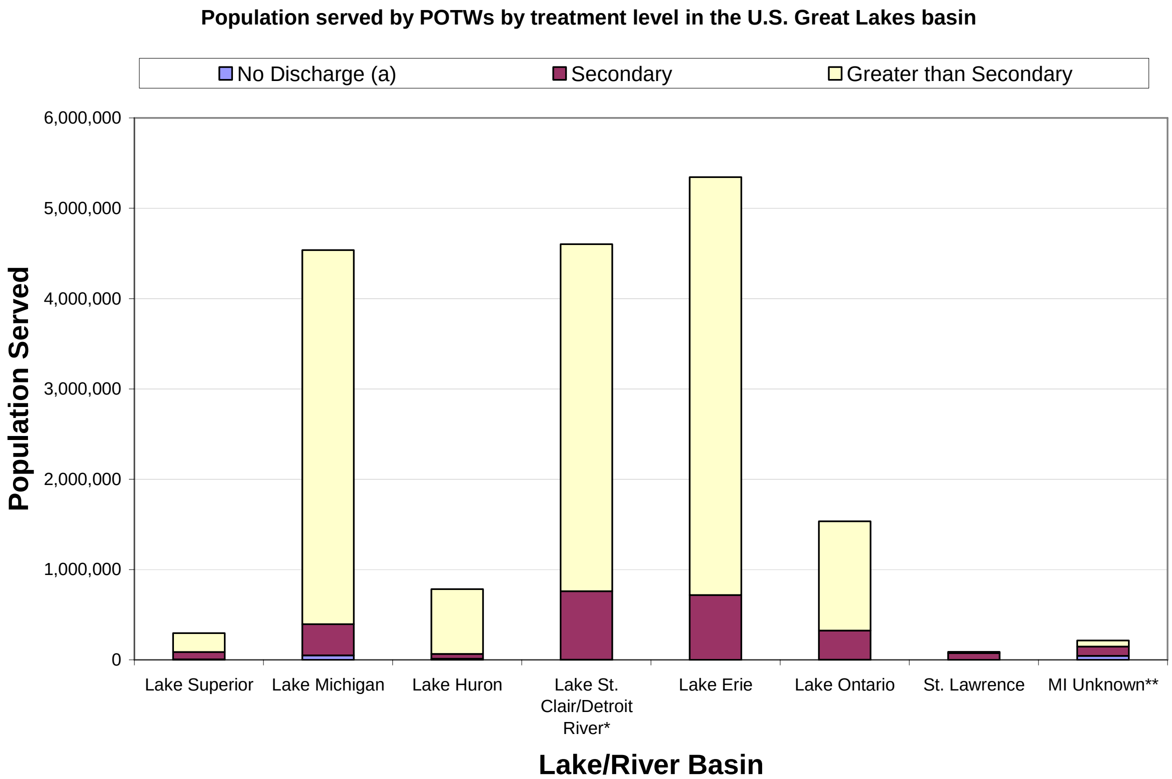
Source: Environment Canada, 2004 http://www.ec.gc.ca/etad/default.asp?lang=En&n=023194F5-1#general



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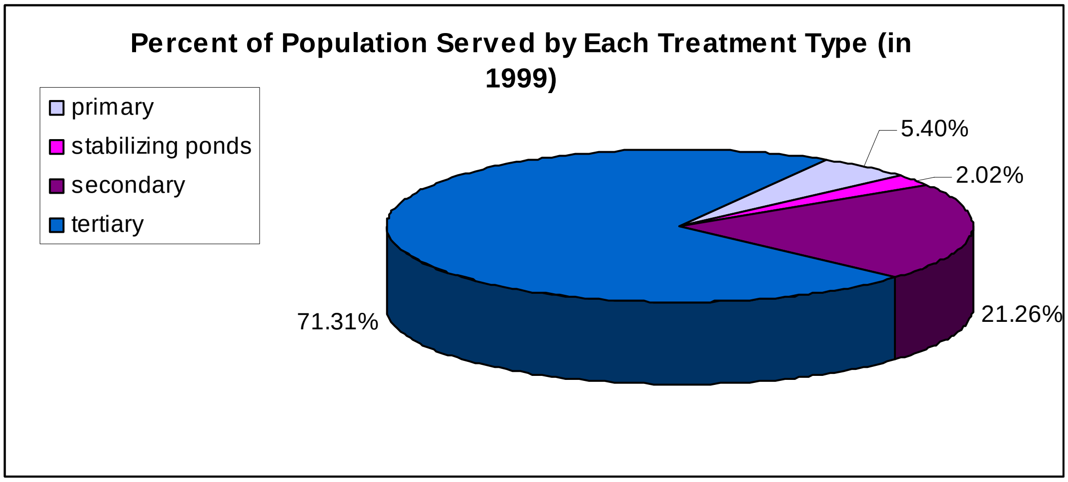

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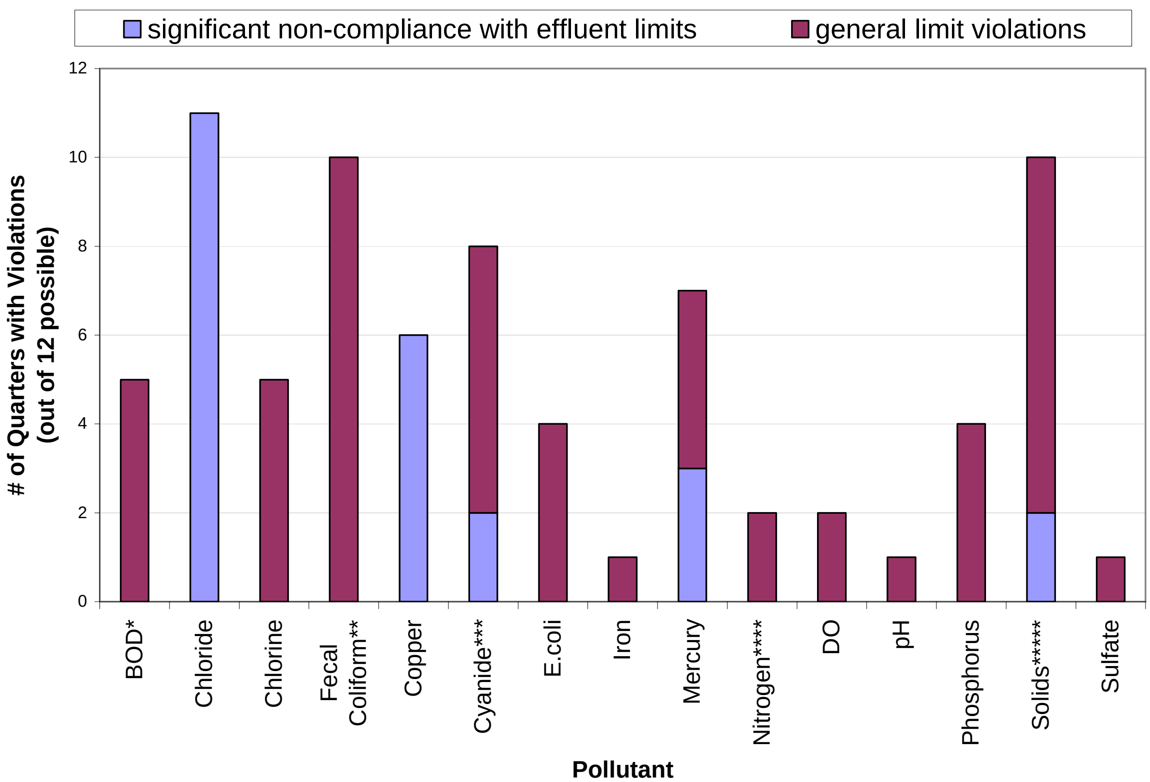

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Source: U.S. EPA. "Enforcement & Compliance History Online (ECHO)." *Compliance and Enforcement.* September 2006. U.S. EPA, Office of Enforcement and Compliance Assurance. http://www.epa.gov/echo/index.html (Accessed September27, 2006).

Natural Groundwater Quality and Human-Induced Changes

Indicator #7100

Assessment: Not Assessed

Note: This indicator report uses data from the Grand River watershed only and may not be representative of groundwater conditions throughout the Great Lakes basin.

Purpose

- To measure groundwater quality as determined by the natural chemistry of the bedrock and overburden deposits, as well as any changes in quality due to anthropogenic activities; and
- To address groundwater quality impairments, whether they are natural or human induced in order to ensure a safe and clean supply of groundwater for human consumption and ecosystem functioning.

Ecosystem Objective

The ecosystem objective for this indicator is to ensure that groundwater quality remains at or approaches natural conditions.

State of the Ecosystem

Background

Natural groundwater quality issues and human induced changes in groundwater quality both have the potential to affect our ability to use groundwater safely. Some constituents found naturally in groundwater renders some groundwater reserves inappropriate for certain uses. Growing urban populations, along with historical and present industrial and agricultural activity, have caused significant harm to groundwater quality, thereby obstructing the use of the resource and damaging the environment. Understanding natural groundwater quality provides a baseline from which to compare, while monitoring anthropogenic changes can allow identification of temporal trends and assess any improvements or further degradation in quality.

Natural Groundwater Quality

The Grand River watershed can generally be divided into three distinct geological areas; the northern till plain, the central region of moraines with complex sequences of glacial, glaciofluvial and glaciolacustrine deposits, and the southern clay plain. These surficial overburden deposits are underlain by fractured carbonate rock (predominantly dolostone). The groundwater resources of the watershed include regional-scale unconfined and confined overburden and bedrock aquifers as well as discontinuous local-scale deposits which contain sufficient groundwater to meet smaller users needs. In some areas of the watershed (e.g. Whitemans Creek basin) the presence of high permeability sands at ground surface and or a high water table leads to unconfined aquifers which are highly susceptible to degradation from surface contaminant sources.

The natural quality of groundwater in the watershed for the most part is very good. The groundwater chemistry in both the overburden and bedrock aquifers is generally high in dissolved inorganic constituents (predominantly calcium, magnesium, sodium, chloride and sulphate). Measurements of total dissolved solids (TDS) suggest relatively "hard" water throughout the watershed. For example, City of Guelph production wells yield water with hardness measured from 249 mg/l to 579 mg/l, which far exceeds the aesthetic Ontario Drinking Water Objective of 80 mg/l to 100 mg/l. Elevated concentrations of trace metals (iron and manganese) have also been identified as ambient quality issues with the groundwater resource.

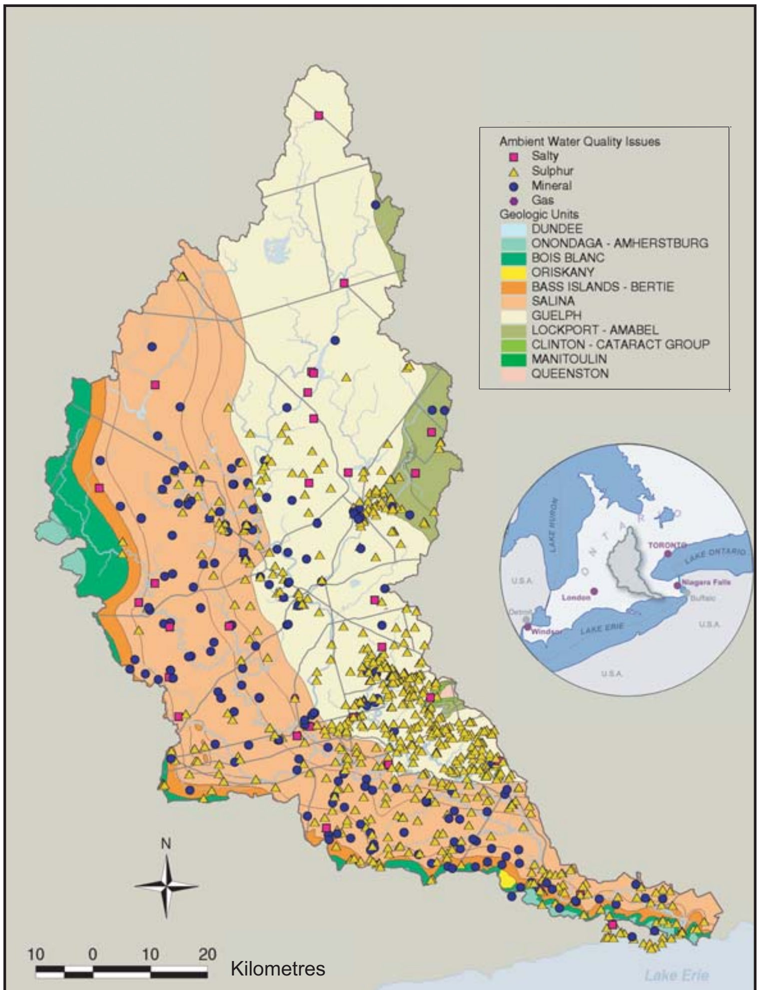

Figure 1. Bedrock wells with natural quality issues in the Grand River watershed.
Source: Grand River Conservation Authority

Figures 1 and 2 illustrate water quality problems observed in bedrock and overburden wells, respectively. These figures are based on a qualitative assessment of well water at the time of drilling as noted on the Ontario Ministry of Environment's water well record form. The majority of these wells were installed for domestic or livestock uses. Overall, between 1940 and 2000, less than 1% (approximately 1131 wells) of all the wells drilled in the watershed reported having a water quality problem. Of the wells exhibiting a natural groundwater problem about 90% were bedrock wells while the other 10% were completed in the overburden. The most frequently noted quality problem associated with bedrock wells was high sulphur content (76% of bedrock wells with quality problems). This is not surprising, as sulphur is easy to detect due to its distinctive and objectionable odour. Generally, three bedrock formations commonly intersected within the watershed contain most of the sulphur wells: the Guelph Formation, the Salina Formation, and the Onondaga-Amherstburg Formation. The Salina Formation forms the shallow bedrock under the west side of the watershed while the Guelph underlies the east side of the watershed.

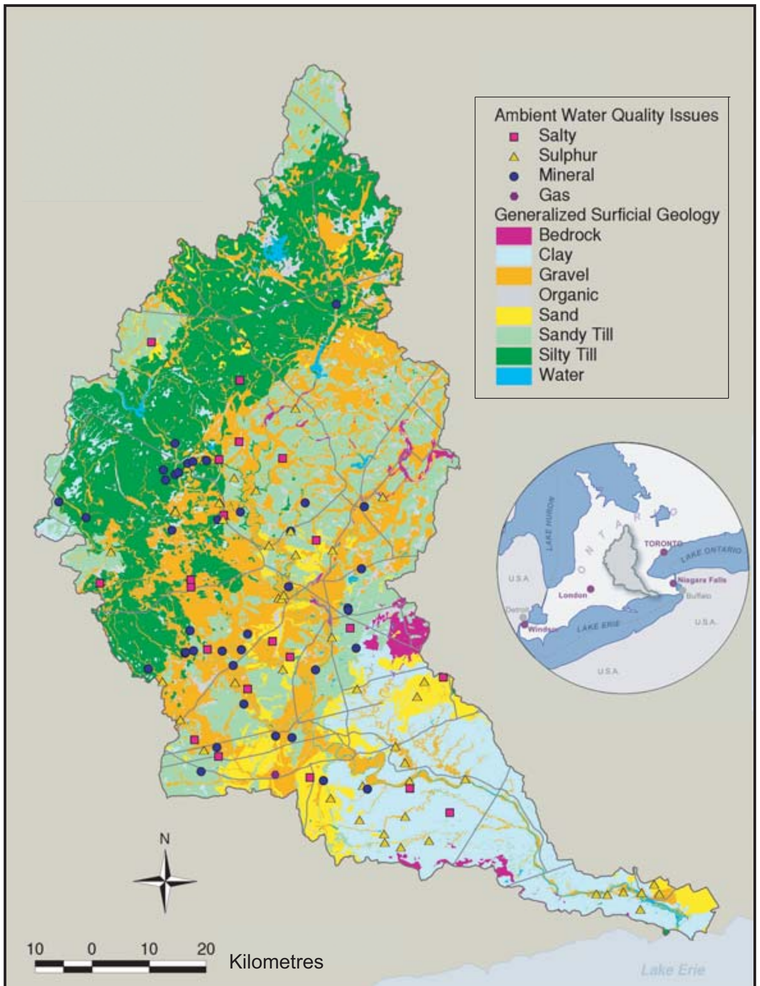

Figure 2. Overburden wells with natural quality issues in the Grand River watershed.
Source: Grand River Conservation Authority

Additional quality concerns noted in the water well records include high mineral content and salt. About 20% of the reported quality concerns in bedrock wells were high mineral content while 4% reported salty water. Similar concerns were noted in overburden wells where reported problems were sulphur (42%), mineral (34%), and salt (23%).

<u>*Human Induced Changes to Groundwater Quality*</u>

Changes to the quality of groundwater from anthropogenic activities associated with urban sprawl, agriculture and industrial operations have been noted throughout the watershed. Urban areas within the Grand River watershed have been experiencing considerable growth over the past few decades. The groundwater quality issues associated with human activity in the watershed include: chloride, industrial chemicals (e.g. trichloroethylene (TCE)), and agricultural impacts (nitrate, bacteria, and pesticides). These contaminants vary in their extent from very local impact (e.g. bacteria) to widespread impact (e.g. chloride). Industrial contaminants tend to be point sources, which generally require very little concentration to impact significant groundwater resources.

Chloride

Increasing chloride concentrations in groundwater have been observed in most municipal wells in the urban portions of the watershed. This increase has been attributed to winter deicing of roads with sodium chloride (salt). Detailed studies carried out by the Regional Municipality of Waterloo have illustrated the impact of road salting associated with increased urban development to groundwater captured by two municipal well fields. Figure 3 shows the temporal changes in chloride concentration for the two well fields investigated in this study. Wells A, B, and C, are from the first well field while wells D and E are from the second well field. In 1967 land use within the capture zone of the first field was 51% rural and 49% urban, while in the second well field capture zone the land use was 94% rural and 6% urban. By 1998, the area within the first well field capture zone had been completely converted to urban land while in the second well field capture zone 60% of the land remained rural.

Although wells from both well fields show increased chloride levels, wells A, B, and C in the heavily urbanized capture zone show a greater increase in chloride concentrations than do wells D and E in the predominantly rural capture zone. For example, well B showed a change in chloride concentration from 16.8 mg/l in 1960, to 260 mg/l in 1996, where as well D showed a change from 3 mg/l in 1966, to 60 mg/l in 1996. This indicates that chloride levels in groundwater can be linked to urban growth and its associated land uses (i.e. denser road network). The Ontario Drinking Water Objective for chloride had been

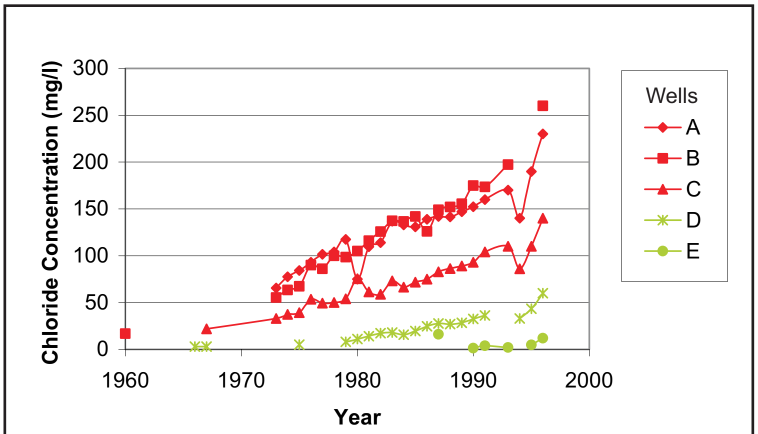

Figure 3. Chloride levels in selected groundwater wells in the Regional Municipality of Waterloo. Red indicates wells from one area/well field. Green indicates wells from a different area/well field.
Source: Stanley Consulting, 1998

established at 250 mg/l, although this guideline is predominantly for aesthetic reasons, the issue of increasing chloride levels should be addressed.

Industrial Contaminants

Groundwater resources in both the overburden and bedrock deposits within the Grand River watershed have been impacted by contamination of aqueous and non-aqueous contaminants which have entered the groundwater as a result of industrial spills or discharges, landfill leachates, leaky storage containers, and poor disposal practices. A significant number of these chemicals are volatile organic compounds (VOCs). Contamination by VOCs such as TCE, have impacted municipal groundwater supplies in several communities in the watershed. For example, by the year 1998, five of the City of Guelph's 24 wells were taken out of service due to low-level VOC contamination. These wells have a combined capacity of 10,000 to 12,000 m^3/day and represent about 15% of the City's permitted water-taking capacity. As a second example, contamination of both a shallow aquifer and a deeper municipal aquifer with a variety of industrial chemicals (including toluene, chlorobenzene, 2,4-D, 2,4,5-T) emanating from a chemical plant in the Region of Waterloo led to the removal of municipal wells from the water system in the town of Elmira.

Agricultural and Rural Impacts

Groundwater quality in agricultural areas is affected by activities such as pesticide application, fertilizer and manure applications on fields, storage and disposal of animal wastes and the improper disposal and spills of chemicals. The groundwater contaminants from these activities can be divided into three main groups: nitrate, bacteria and pesticides. For example, the application of excessive quantities of nutrients to agricultural land may impact the quality of the groundwater. Excess nitrogen applied to the soil to sustain crop production is converted to nitrate with infiltrating water and hence transported to the water table. Seventy-six percent of the total land area in the Grand River watershed is used for agricultural purposes and thus potential and historical contamination of the groundwater due to these activities is a concern.

Land use and nitrate levels measured in surface water from two sub-watersheds, the Eramosa River and Whitemans Creek, are

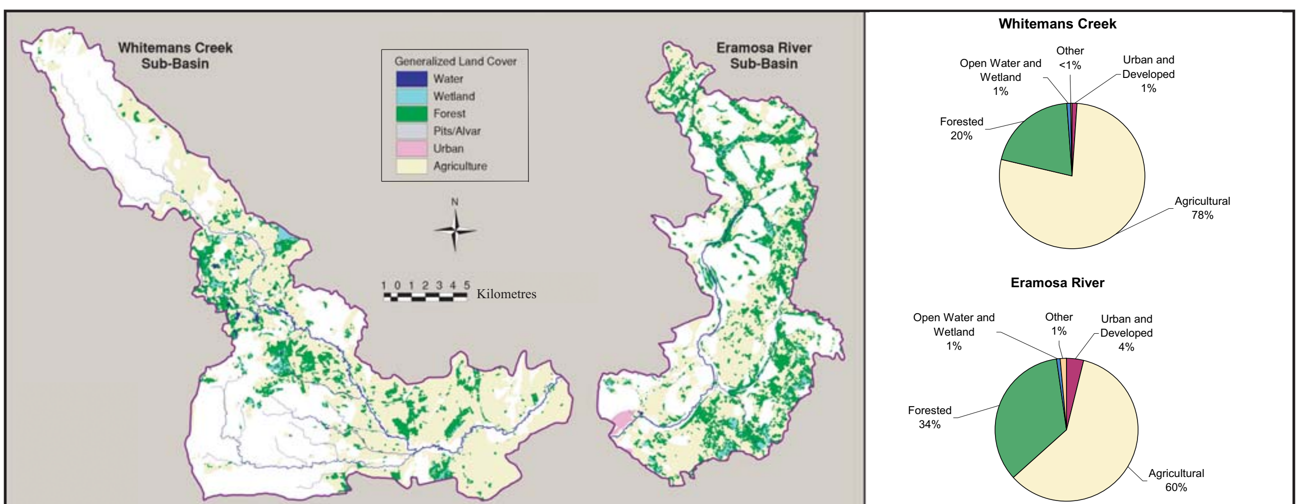

Figure 4. Land cover on moraine systems and areas that facilitate high to very high groundwater recharge of the Whitemans Creek and Eramosa River sub-watersheds: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority

used to illustrate the effects of agricultural activities on groundwater quality and the quality of surface water.

In the Whitemans Creek sub-watershed, approximately 78% of the land classified as groundwater recharge area is covered with agricultural uses, and only 20% is forested. In the Eramosa subwatershed about 60% of the significant recharge land is used for agricultural purposes with approximately 34% of the land being covered with forest (Figure 4). Both of these tributary streams are considered predominantly groundwater-fed streams, meaning that the majority of flow within them is received directly from groundwater discharge.

Average annual concentrations of nitrate measured in the Eramosa River and Whitemans Creek from 1997 to 2003 are shown in Figure 5. Average annual concentration of nitrate measured in Whitemans Creek between 1997 and 2003 were 2.5 to 8 times higher than those measured in the Eramosa River. The higher nitrate levels measured in Whitemans Creek illustrate the linkage between increased agricultural activity and groundwater contamination and its impact on surface water quality. In addition to the agricultural practices in the Whitemans Creek subwatershed, the observed nitrate concentrations may also be linked to rural communities with a high density of septic systems that leach nutrients to the subsurface.

Manure spreading on fields, runoff from waste disposal sites, and septic systems may all provide a source of bacteria to groundwater. Bacterial contamination in wells in agricultural areas is common, however, this is often due to poor well construction allowing surface water to enter the well and not indicative of widespread aquifer contamination. Shallow wells are particularly vulnerable to bacterial contamination.

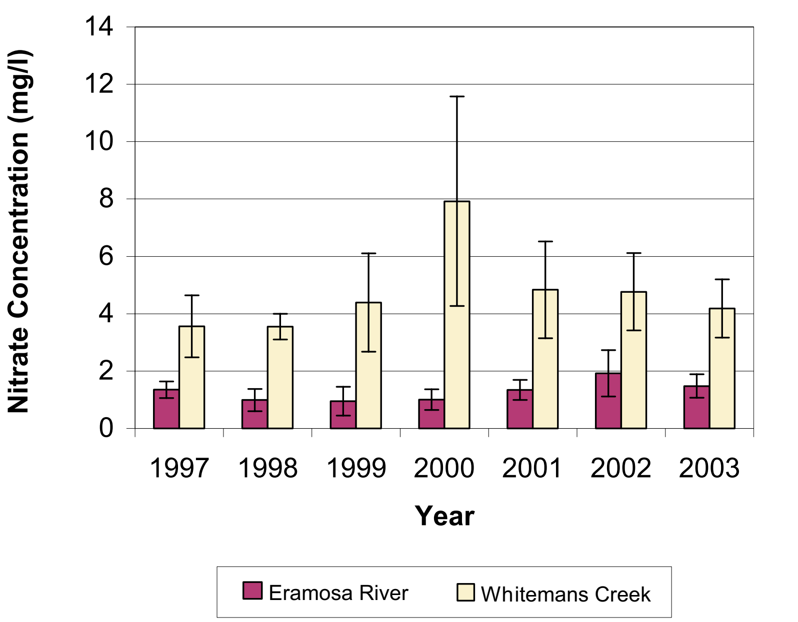

Figure 5. Average annual concentrations of nitrate measured in the Eramosa River and Whitemans Creek from 1997 to 2003. (Also shown on the bar graphs is the standard error of measurement)
Source: Ontario Provincial Water Quality Monitoring Network, 2003.

Pressures

The population within the Grand River watershed is expected to increase by over 300,000 people in the next 20 years. The urban sprawl and industrial development associated with this population growth, if not managed appropriately, will increase the chance for contamination of groundwater resources. Intensification of agriculture will lead to increased potential for pollution caused by nutrients, pathogens and pesticides to enter the groundwater supply and eventually surface water resources. While largely unknown at this time, the effects of climate change may lead to decreased groundwater resources, which may concentrate existing contaminant sources.

Management Implications

Protecting groundwater resources generally requires multifaceted strategies including regulation, land use planning, water resources management, voluntary adoption of best management practices and public education. Programs to reduce the amount of road salt used for deicing will lead to reductions in chloride contamination in groundwater. For example, the Regional of Waterloo (the largest urban community in the watershed) in cooperation with road maintenance departments has been able to decrease the amount of road salt applied to Regional roads by 27% in just one winter season.

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Authors' Commentary

While there is a large quantity of groundwater quality data available for the various aquifers in the watershed, this data has not been consolidated and evaluated in a comprehensive or systematic way. Work is needed to bring together this data and incorporate ongoing groundwater monitoring programs. An assessment of the groundwater quality across Ontario is currently being undertaken through sampling and analysis of groundwater from the provincial groundwater-monitoring network (PGMN) wells (includes monitoring stations in the Grand River watershed). Numerous watershed municipalities also have had ongoing monitoring programs, which examine the quality of groundwater as a source of drinking water in place for a number of years. Integrating this data along with data contained in various site investigations will allow for a more comprehensive picture of groundwater quality in the watershed.

Last Updated

State of the Great Lakes 2005

Groundwater and Land: Use and Intensity

Indicator #7101

Assessment: Not Assessed

Note: This indicator report uses data from the Grand River watershed only and may not be representative of groundwater conditions throughout the Great Lakes basin.

Purpose

- To measure water use and intensity and land use and intensity;
- To infer the potential impact of land and water use on the quantity and quality of groundwater resources as well as evaluate groundwater supply and demand; and
- To track the main influences on groundwater quantity and quality such as land and water use to ensure sustainable high quality groundwater supplies.

Ecosystem Objective

The ecosystem objective for this indicator is to ensure that land and water use does not negatively impact groundwater supplies/resources.

State of the Ecosystem

Background

Land use and intensity has the potential to affect both groundwater quality and quantity. Similarly, water use and intensity (i.e. demand) can impact the sustainability of groundwater supplies. In addition, groundwater use and intensity can impact streams and creeks, which depend on groundwater for base flows to sustain aquatic plant and animal communities.

Land use and intensity

The Grand River watershed can generally be divided into three distinct geological areas; the northern till plain, central moraines with complex sequences of glacial, glaciofluvial and glaciolacustrine deposits, and the southern clay plain. These surficial overburden deposits are underlain by fractured carbonate rock (predominantly dolostone). The groundwater resources of the watershed include regional-scale unconfined and confined overburden and bedrock aquifers as well as discontinuous local-scale deposits which contain sufficient groundwater to meet smaller users' needs. In some areas of the watershed (e.g. Whiteman's Creek basin) the presence of high permeability sands at ground surface and/or a high water table leads to unconfined aquifers which are highly susceptible to contamination from surface contaminant sources.

Agricultural and rural land uses predominate in the Grand River watershed. Approximately 76% of the watershed land area is used for agriculture (Figure 1). Urban development covers about

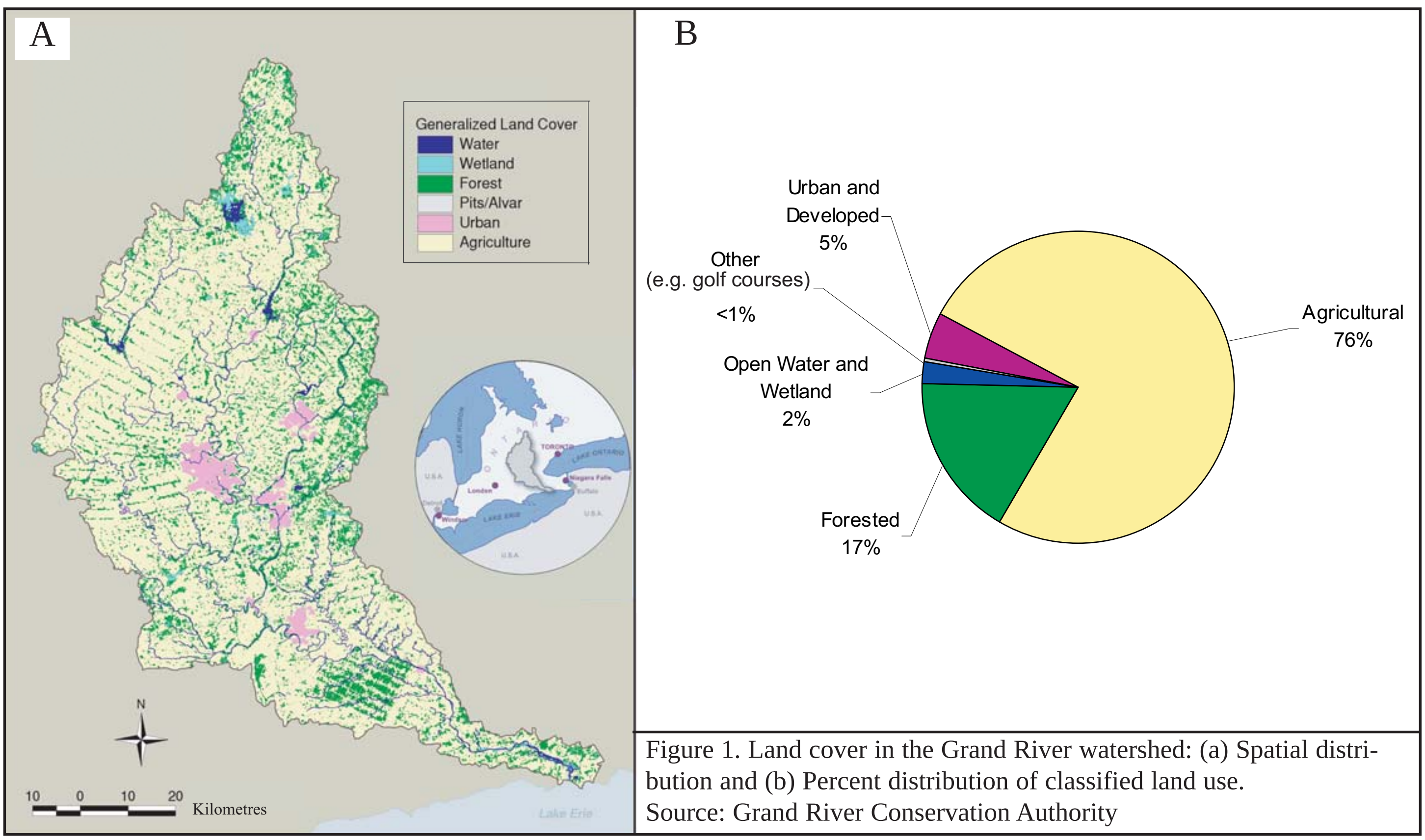


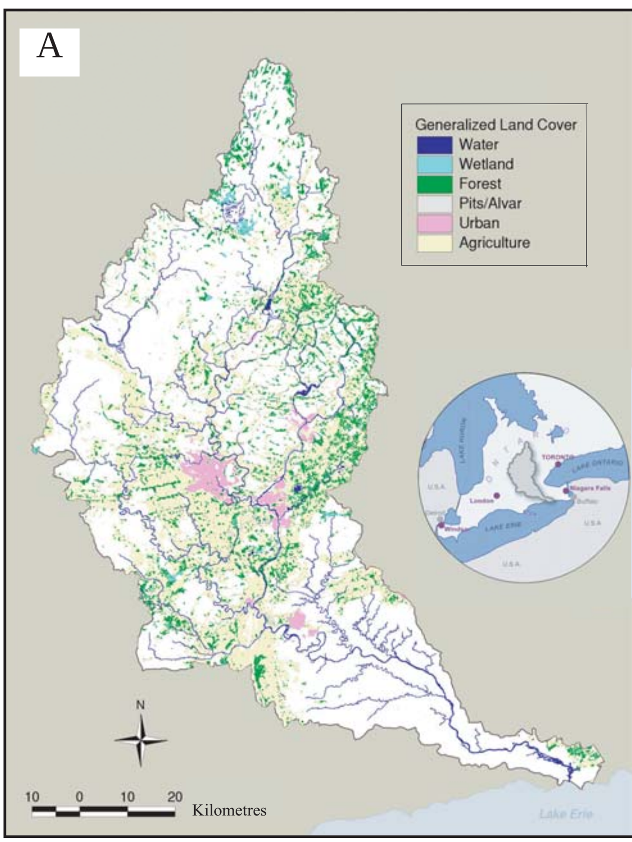
Figure 1. Land cover in the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority

5% of the watershed area while forests cover about 17%. The largest urban centres, including Kitchener, Waterloo, Cambridge and Guelph, are located in the central portion of the watershed and are situated on or in close proximity to many of the complex moraine systems that stretch across the watershed (Figure 1). The moraines and associated glacial outwash area in the watershed form a complex system of sand and gravel layers separated by less permeable till layers. Together with the sand plain in the southwest portion of the watershed these units provide significant groundwater resources. The majority of the groundwater recharge in the watershed is concentrated in a land area that covers approximately 38% of the watershed. Figure 2 illustrates the land cover associated with those areas that have high recharge potential.

Land use on these moraines and significant recharge areas can have major influence on both groundwater quantity and quality (Figure 2). Intensive cropping practices with repeated manure and fertilizer applications have the potential to impact groundwater quality while urban development can interrupt groundwater recharge and impact groundwater quantity. About 67% of the significant recharge areas are in agricultural production while 23% and 8% of the recharge areas are covered with forests and urban development respectively. Since the moraine systems and recharge areas in the Grand River watershed provide important ecological, sociological and economical services to the watershed, they are important watershed features that must be maintained to ensure sustainable groundwater supplies.

Land use directly influences the ability of precipitation to recharge shallow aquifers. Urban development such as the paving of roads and building of structures intercepts precipitation and facilitates the movement of water off the land in surface runoff, which subsequently reduces groundwater recharge of shallow aquifers. A significant portion (62%) of the urban area in the Grand River watershed tends to be concentrated in the highly sensitive groundwater recharge areas (Figure 3). Development is continuing in these sensitive areas. For example, of the total kilometres of new roads built between 2000 and 2004 in the Region of Waterloo, about half of them were situated in the more sensitive areas.

Land uses that protect groundwater recharge such as some agricultural land use and forested areas need to be protected to ensure groundwater recharge. About 34% and 51% of the watershed's agricultural and forested land cover is located in the significant recharge areas. Strategic development is needed to protect these recharge areas to protect groundwater recharging function in the watershed.



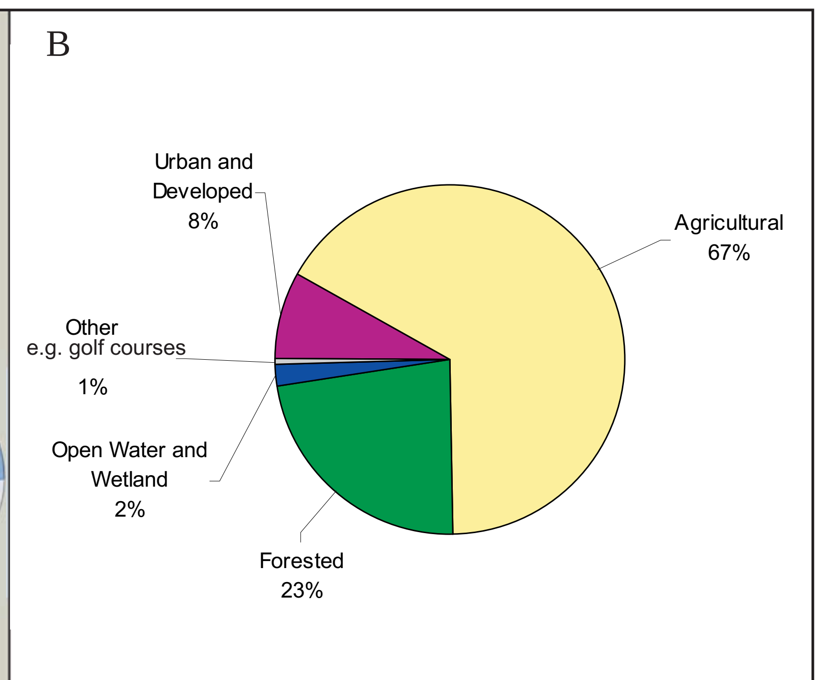


Figure 2. Land cover on moraine systems and areas that facilitate high or very high groundwater recharge of the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority

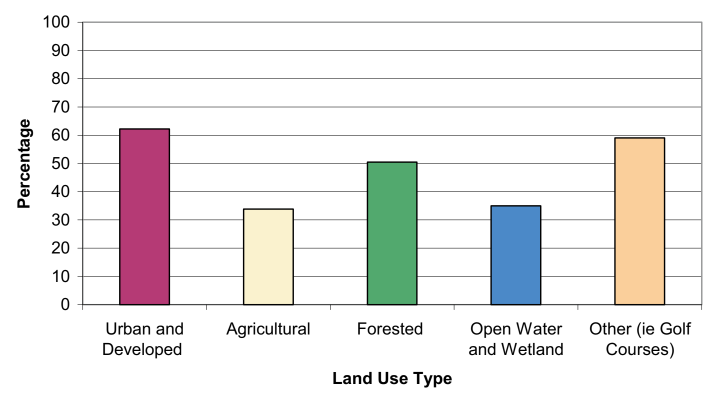


Figure 3. Percentage of land use type in significant recharge areas in the Grand River watershed.
Source: Grand River Conservation Authority

Groundwater use and intensity

Groundwater in the Grand River watershed is used for a range of activities including domestic, municipal, public, agricultural, and industrial/commercial supplies. It is estimated that approximately 80% of the 875,000 watershed residents use groundwater as their primary source of potable water.

Between 1940 and 2003, over 37,000 wells were constructed in the Grand River watershed. Approximately 79% of these wells (or 29,683 wells) are, or were, used for domestic water supplies (Figure 4). However, this represents only 3% of the total annual groundwater takings in the watershed (Figure 5). The largest users of groundwater in the watershed are municipalities (30%) who use the water to provide potable water to their residents. Industries, commercial developments, aggregate washing, dewatering and remediation also withdraw significant amounts of groundwater (43%, combined). Aquaculture is a significant user of groundwater at approximately 13% of the total annual groundwater takings in the watershed.

Even though total annual groundwater withdrawals identify municipal takings as the most significant use of groundwater, seasonal demands in selected areas can be significant. Irrigation becomes the second largest use of water in July in the Grand River watershed. Approximately 60% of all irrigation is done with groundwater. Therefore, this seasonal demand can have a significant impact on local groundwater fed streams and the aquatic life that inhabits them. Although the irrigated land in the Grand River watershed is less than 1% of the total land area, increasing trends in irrigation (Figure 6) places added stress on these local groundwater-dependant ecosystems.

Climatic factors and population growth can also impact the demand for groundwater resources. The number of new wells drilled since 1980 grew steadily until 1989 (Figure 7). The number of new wells drilled peaked between 1987 and 1989, which coincides with a period of lower flow in the river. The average annual river flows illustrated in Figure 7 represents conditions where average, below average and above average streamflow were measured. The 1987-1989 period had below average streamflow suggesting it was dryer than normal and that watershed residents were searching for new groundwater supplies. The same occurrence is illustrated again in 1998-1999. The cumulative impact of both climate effects and increased population growth (Figure 8) likely contributes to greater demand for groundwater supplies.

Pressures

Urbanization and associated development on sensitive watershed landscapes that facilitate groundwater recharge is a significant threat to groundwater resources in the Grand River watershed. Eliminating this important watershed function will directly

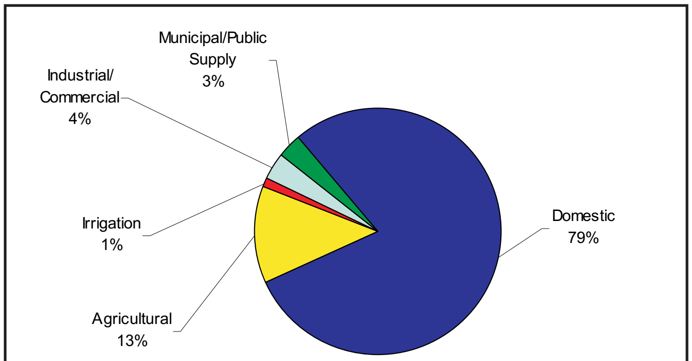


Figure 4. Distribution of groundwater wells by primary use in the Grand River watershed.
Source: Ontario Ministry of the Environment Water Well Database, 2003

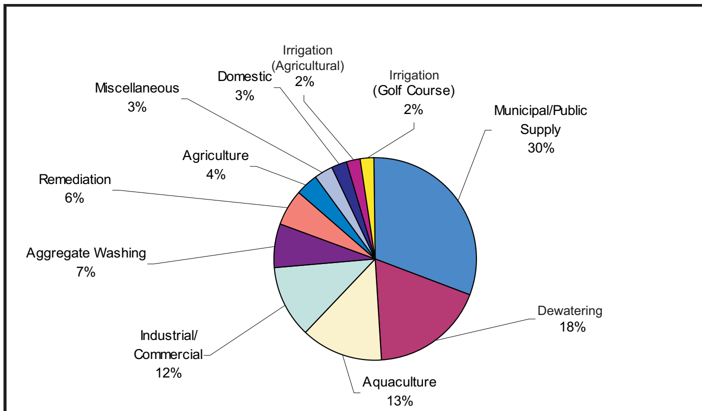


Figure 5. Percentage of total annual groundwater takings in the Grand River watershed from designated uses.
Source: Modified from Bellamy and Boyd, 2004

impact the quantity of groundwater supplies for watershed residents. Therefore, it is essential that municipalities and watershed residents protect the moraine systems and significant recharge areas to ensure future groundwater supplies.

Population growth with continued urban development and agricultural intensification are the biggest threats to groundwater supplies in the Grand River watershed. It is estimated that the population of the watershed will increase by approximately 300,000 people in the next 20 years (Figure 8). The biggest single users of groundwater are municipalities for municipal drinking water supplies, although industrial users, including aggregate and dewatering operations, use a significant amount of groundwater. Municipalities, watershed residents and industries will need to increase their efforts in water conservation as well as continue to seek out new or alternate supplies.

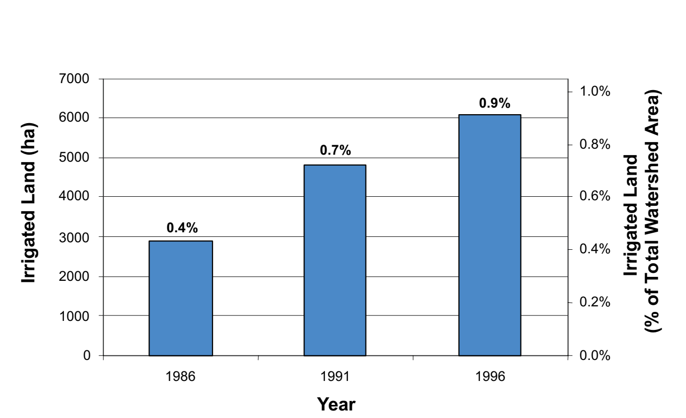


Figure 6. Changes in amount of irrigated land in the Grand River watershed (percentage of total watershed area irrigated).
Source: Statistics Canada data for 1986, 1991, and 1996

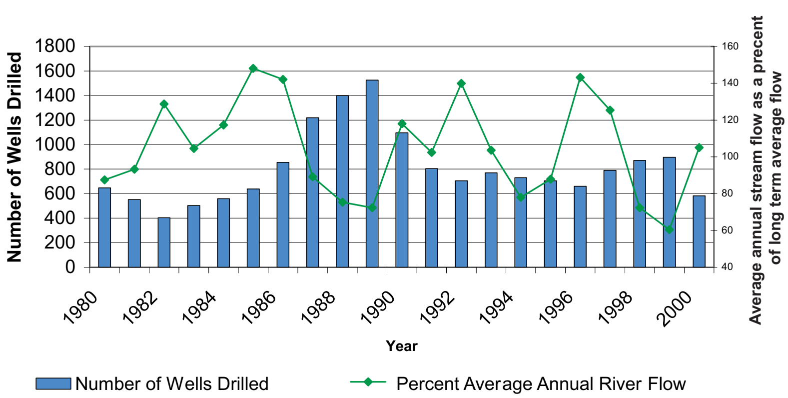


Figure 7. Number of new wells drilled each year (bars). Annual average stream flow (as a percentage on long term average) in the Grand River watershed illustrating below average, and average climatic conditions (green line).
Source: Ontario Ministry of the Environment Water Well Database, 2003

Climate influence on groundwater resources in the Grand River watershed cannot be underestimated. It is evident that during times with below average precipitation, there is increased demand for groundwater resources for both the natural environment and human uses. In addition, climate change will likely redistribute precipitation patterns throughout the year, which will likely impact groundwater resources in the watershed.

Management Implications

Land use and development has a direct effect on groundwater quantity and quality. Therefore, land use planning must consider watershed functions such as groundwater recharge when directing future growth. Municipal growth strategies should direct growth and development away from sensitive watershed landscapes such as those areas that facilitate groundwater recharge. Efforts in recent years have focussed on delineating wellhead protection zones, assessing the threats and understanding the regional hydrogeology. Through the planning process, municipalities such as the Region of Waterloo, City of Guelph and the County of Wellington have recognized the importance of protecting recharge to maintain groundwater resources and have been taking steps to protect this watershed function. These initiatives include limiting the amount of impervious cover in sensitive areas and capturing precipitation with rooftop collection systems. By permitting development that facilitates groundwater recharge or redirecting development to landscapes that are not as sensitive, important watershed functions can be protected to ensure future groundwater supplies.

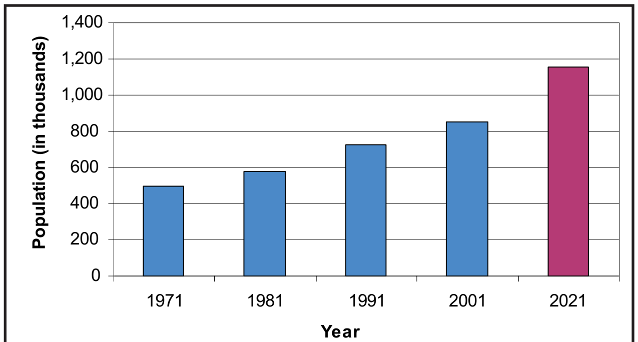


Figure 8. Estimated population in the Grand River watershed including future projections (burgundy bar).
Source: Dorfman, 1997 and Grand River Conservation Authority, 2003

Water conservation measures should be actively promoted and adopted in all sectors of society. Urban communities must actively reduce consumption while rural communities require management plans to strategically irrigate using high efficiency methods and appropriate timing.

Acknowledgments
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Authors' Commentary

Understanding the impact of water use on the groundwater resources in the watershed will require understanding the availability of water to allow sustainable human use while still maintaining healthy ecosystems. Assessing groundwater availability and use at appropriate scales is an important aspect of water balance calculations in the watershed. In other words, assessing water and land use at the larger watershed scale masks more local issues such as the impact of extensive irrigation.

Consistent and improved monitoring and data collection are required to accurately estimate groundwater demand as well as determine long-term trends in land use. For example, linking groundwater permits to actual well log identification numbers will assist with understanding the spatial distribution of groundwater takings. Furthermore, groundwater permit holders should be required to report actual water use as opposed to permitted use. This will help estimate actual water use and therefore the true impact on the groundwater system.

Last Updated

State of the Great Lakes 2005

Base Flow Due to Groundwater Discharge
Indicator #7102

Overall Assessment
Status: **Mixed**
Trend: **Deteriorating**
Primary Factors Determining Status and Trend: **It is estimated that human activities have detrimentally impacted groundwater discharge on at least a local scale in some areas of the Great Lakes basin and that discharge is not significantly impaired in other areas.**

Lake-by-Lake Assessment
Lake Superior
Status: Not Assessed
Trend: Undetermined

Lake Michigan
Status: Not Assessed
Trend: Undetermined

Lake Huron
Status: Not Assessed
Trend: Undetermined

Lake Erie
Status: Not Assessed
Trend: Undetermined

Lake Ontario
Status: Not Assessed
Trend: Undetermined

Purpose
•To measure the contribution of base flow due to groundwater discharge to total stream flow; and
•To detect the impacts of anthropogenic factors on the quantity of the groundwater resource.

Ecosystem Objective
Base flow due to the discharge of groundwater to the rivers and inland lakes and wetlands of the Great Lakes basin is a significant and often major component of stream flow, particularly during low flow periods. Base flow frequently satisfies flow, level, and temperature requirements for aquatic species and habitat. Water supplies and the capacity of surface water to assimilate wastewater discharge are also dependent on base flow. Base flow due to groundwater discharge is therefore critical to the maintenance of water quantity and quality and the integrity of aquatic species and habitat.

State of the Ecosystem

Background

A significant portion of precipitation over the inland portion of the Great Lakes basin returns to the atmosphere by evapo-transpiration. Water that does not return to the atmosphere either flows across the ground surface or infiltrates into the subsurface and recharges groundwater. Some of this water is subsequently removed by consumptive uses such as irrigation and water bottling. Water that flows across the ground surface discharges into surface water features (rivers, lakes, and wetlands) and then flows toward and eventually into the Great Lakes. The component of stream flow due to runoff from the ground surface is rapidly varying and transient, and results in the peak discharges of a stream.

Water that infiltrates into the subsurface and recharges groundwater also results in flow toward the Great Lakes. Most recharged groundwater flows at relatively shallow depths at local scales and discharges into adjacent surface water features. However, groundwater also flows at greater depths at regional scales and discharges either directly into the Great Lakes or into distant surface water features. The quantities of groundwater flowing at these greater depths can be significant locally but are generally believed to be modest relative to the quantities flowing at shallower depths. Groundwater discharge to surface water features in response to precipitation is greatly delayed relative to surface runoff. The stream flow resulting from groundwater discharge is, therefore, more uniform.

Base flow is the less variable and more persistent component of total stream flow. In the Great Lakes region, groundwater discharge is often the dominant component of base flow; however, various human and natural factors also contribute to base flow. Flow regulation, the storage and delayed release of water using dams and reservoirs, creates a stream flow signature that is similar to that of groundwater discharge. Lakes and wetlands also moderate stream flow, transforming rapidly varying surface runoff into more slowly varying flow that approximates the dynamics of groundwater discharge. It is important to note that these varying sources of base flow affect surface water quality, particularly with regard to temperature. All groundwater discharge contributes to base flow but not all base flow is the result of groundwater discharge.

Status of Base Flow

Base flow is frequently determined using a mathematical process known as hydrograph separation. This process uses stream flow monitoring information as input and partitions the observed flow into rapidly and slowly varying components, surface runoff and base flow, respectively. The stream flow data that are used in these analyses are collected across the Great Lakes basin using networks of stream flow gauges that are operated by the United States Geological Survey (USGS) and Environment Canada. Neff *et al*. (2005) summarize the calculation and interpretation of base flow for 3,936 gauges in Ontario and the Great Lakes states using six methods of hydrograph separation and length-of-record stream flow monitoring information for the periods ending on December 31, 2000 and September 30, 2001, respectively. The results reported by Neff *et al*. (2005) are the basis for the majority of this report. Results corresponding to the UKIH method of hydrograph separation (Piggott *et al*. 2005) are referenced throughout this report in order to maintain consistency with the previous report for this indicator; however, results calculated using the five other methods are considered to be equally probable outcomes. Figure 1 illustrates the daily stream flow monitoring information and the results of hydrograph separation for the Nith River at New Hamburg, Ontario for January 1 to December 31, 1993. The rapidly varying response of stream flow to precipitation and snow melt are in contrast to the more slowly varying base flow.

Application of hydrograph separation to daily stream flow monitoring information results in lengthy time series of output. Various measures are used to summarize this output; for example, base flow index is a simple, physical measure of the contribution of base flow to stream flow that is appropriate for use in regional scale studies. Base flow index is defined as the average rate of base flow relative to the average rate of total stream flow, is unitless, and varies from zero to one where increasing values indicate an increasing contribution of base flow to stream flow. The value of base flow index for the data shown in Figure 1 is 0.28, which implies that 28% of the observed flow is estimated to be base flow. Neff *et al*. (2005) used a selection of 960 gauges in Ontario and the Great Lakes states to interpret base flow. Figure 2 indicates the distribution of the values of base flow index calculated for the selection of gauges relative to the gauged and ungauged portions of the Great Lakes basin. The variability of base flow within the basin is apparent; however, further processing of the information is required to differentiate the component of base flow that is due to groundwater discharge and the component that is due to delayed flow through lakes and wetlands upstream of the gauges. An approach to the differentiation of base flow calculated using hydrograph separation into these two components is summarized in the following paragraphs of this report. Variations in the density of the stream flow gauges and discontinuities in the coverage of monitoring are also apparent in Figure 2 and may have significant implications relative to the interpretation of base flow.

The values of base flow index calculated for the selection of gauges using hydrograph separation are plotted relative to the extents of surface water upstream of each of the gauges in Figure 3 where the extents of surface water are defined as the area of lakes and wetlands upstream of the gauges relative to the total area upstream of the gauges. While there is considerable scatter among the values, the expected tendency for larger values of base flow index to be associated with larger extents of surface water is confirmed. Neff *et al*. (2005) modeled base flow index as a function of surficial geology and the spatial extent of surface water. Surficial geology is assumed to be responsible for differences in groundwater discharge and is classified into coarse and fine textured sediments, till, shallow bedrock, and organic deposits.

The modeling process estimates a value of base flow index for each of the geological classifications, calculates the weighted averages of these values for each of the gauges based on the extents of the classifications upstream of the gauges, and then modifies the weighted averages as a function of the extent of surface water upstream of the gauges. A non-linear regression algorithm was used to determine the values of base flow index for the geological classifications and the parameter in the surface water modifier that correspond to the best match between the values of base flow index calculated using hydrograph separation and the values predicted using the model. The process was repeated for each of the six methods of hydrograph separation.

Extrapolation of base flow index from gauged to ungauged watersheds was performed using the results of the modeling process. The ungauged watersheds consist of 67 tertiary watersheds in Ontario and 102 eight-digit hydrologic unit code or HUC watersheds in the Great Lakes states. The extents of surface water for the ungauged watersheds are shown in Figure 4 where the ranges of values used in the legend match those used to average the values of base flow index shown in

Figure 3. A component of base flow due to delayed flow through lakes and wetlands appears to be likely over extensive portions of the Great Lakes basin. The distribution of the classifications of geology is shown in Figure 5. Organic and fine textured sediments are not differentiated in this rendering of the classifications because both classifications have estimated values of base flow index due to groundwater discharge in the range of 0.0 to 0.1; however, organic deposits are of very limited extent and represent, on average, less than 2% of the area of the ungauged watersheds. The spatial variation of base flow index shown in Figure 5 resembles the variation shown in Figure 2. However, it is important to note that the information shown in Figure 2 includes the influence of delayed flow through lakes and wetlands upstream of the gauges while this influence has been removed, or at least reduced, in the information shown in Figure 5.

Figure 6 indicates the values of the geological component of base flow index for the ungauged watersheds obtained by calculating the weighted averages of the values for the geological classifications that occur in the watersheds. This map therefore represents an estimate of the length-of-record contribution of base flow due to groundwater discharge to total stream flow that is consistent and seamless across the Great Lakes basin. The pie charts indicate the range of values of the geological component of base flow index for the six methods of hydrograph separation averaged over the sub-basins of the Great Lakes. Averaging the six values for each of the sub-basins yields contributions of base flow due to groundwater discharge of approximately 60% for Lakes Huron, Michigan, and Superior and 50% for Lakes Erie and Ontario. It is important to note that there is frequently greater variability of this contribution within the sub-basins than among the sub-basins as the result of variability of geology that is more uniformly averaged at the scale of the sub-basins.

Mapping the geological component of base flow index, which is assumed to be due to groundwater discharge, across the Great Lakes basin in a consistent and seamless manner is an important accomplishment in the development of this indicator. Additional information is, however, required to determine the extent to which human activities have impaired groundwater discharge. There are various alternatives for the generation of this information. For example, the values of base flow index calculated for the selection of stream flow gauges using hydrograph separation can be compared to the corresponding modeled values. If a calculated value is less than a modeled value, and if the difference is not related to the limitations of the modeling process, then base flow is less than expected based on physiographic factors and it is possible that discharge has been impacted by human activities. Similarly, if a calculated value is greater than a modeled value, then it possible that the increased base flow is the result of human activities such as flow regulation and wastewater discharge. Time series of base flow can also be used to assess these impacts. The previous report for this indicator illustrated the detection of temporal change in base flow using data for watersheds with approximately natural stream flow and with extensive flow regulation and urbanization; however, no attempt has yet been made to systematically assess change at the scale of the Great Lakes basin. Change in base flow over time may be subtle and difficult to quantify (e.g., variations in the relation of base flow to climate) and may be continuous (e.g., a uniform increase in base flow due to aging water supply infrastructure and increasing conveyance losses) or discrete (e.g., an abrupt reduction in base flow due to a new consumptive water use). Change may also be the result of cumulative impacts due to a range of historical and ongoing human activities, and may be more pronounced and readily detected at local scales than at the scales that are typical of continuous stream flow monitoring.

Figure 7 is an alternative view of the data for the Grand River at Galt, Ontario that was previously used to illustrate the impact of flow regulation on base flow. The cumulative depth of base flow calculated annually as the total volume of flow at the location of the gauge during each year divided by the area that is upstream of the gauge, is plotted relative to cumulative total flow. Base flow index is, by definition, the slope of the accumulation of base flow relative to the accumulation of total flow. The change in slope and increase in base flow index from a value of 0.45 prior to the construction of the reservoirs that are located upstream of the gauge to 0.57 following the construction of the reservoirs clearly indicates the impact of active flow regulation to mitigate low and high flow conditions. Calculating and interpreting diagnostic plots such as Figure 7 for hundreds to thousands of stream flow gauges in the Great Lakes basin will be a large and time consuming, but perhaps ultimately necessary, task.

Improving the spatial resolution of the current estimates of base flow due to groundwater discharge would be beneficial in some settings. For example, localized groundwater discharge has important implications in terms of aquatic habitat and it is unlikely that this discharge can be predicted using the current regional estimates of base flow. The extrapolation of base flow information from gauged to ungauged watersheds described by Neff *et al*. (2005) is based on a classification and therefore reduced resolution representation of the Quaternary geology of the basin. Figure 8 compares this classification to the full resolution of the available 1:1,000,000 scale (Ontario Geological Survey 1997) and 1:50,000 scale (Ontario Geological Survey 2003) mapping of the geology of the gauged portion of the Grand River watershed in southern Ontario. Interpretation of base flow in terms of these more detailed descriptions of geology, where feasible relative to the network of stream flow gauges, may result in an improved estimate of the spatial distribution of groundwater discharge for input into functions such as aquatic habitat management.

Estimation of base flow using low flow observations, single “spot” measurements of stream flow under assumed base flow conditions, is another means of improving the spatial resolution of the current prediction of groundwater discharge. Figure 9 illustrates a series of low flow observations performed within the watershed of Duffins Creek above Pickering, Ontario where the observations are standardized using continuous monitoring information and the drainage areas for the observations following the procedure described by Gebert *et al*. (in press) and then classified into quantile groupings of high, intermediate, and low values. The standardized values of low flow illustrate the spatially variable pattern of groundwater discharge that results from the interaction between surficial geology, the complex three-dimensional hydrostratigraphy, topography, and surface water features. Areas of potentially high groundwater discharge may have particularly important implications in terms of aquatic habitat for cold water fish species such as Brook Trout.

Finally, reconciling estimates of base flow generated using differing methods of hydrograph separation, perhaps by interpreting the information in a relative rather than absolute manner, will improve the certainty and therefore performance of base flow as an indicator of groundwater discharge. It may also be possible to assess the source of this uncertainty using chemical and isotopic data in combination with the methods of hydrograph separation if adequate data is available at the scale of the gauged watersheds. Figure 10 compares the values of base flow index calculated for the selection of 960 stream flow gauges in Ontario and the Great Lake states using the PART (Rutledge 1998) and UKIH methods of hydrograph separation. The majority of the values calculated using the PART method are greater than the values calculated using the UKIH method and there is considerable scatter in the differences among the two methods. The average of the differences between the two sets of values is 0.15 and is significant when measured relative to the differences in the estimates of base flow index for the sub-basins of the Great Lakes, which is on the order of 0.1.

Pressures

The discharge of groundwater to surface water features is the end-point of the process of groundwater recharge, flow, and discharge. Human activities impact groundwater discharge by modifying the components of this process where the time scale, and to some extent the severity, of these impacts is a function of hydrogeological factors and the proximity of surface water features. Increasing the extent of impervious surfaces during residential and commercial development and installation of drainage to increase agricultural productivity are examples of activities that may reduce groundwater recharge and ultimately groundwater discharge. Withdrawals of groundwater as a water supply and during dewatering (pumping groundwater to lower the water table during construction, mining, etc.) remove groundwater from the flow regime and may also reduce groundwater discharge. Groundwater discharge may be impacted by activities such as the channelization of water courses that restrict the motion of groundwater across the groundwater and surface water interface. Human activities also have the capacity to intentionally, or unintentionally, increase groundwater discharge. Induced storm water infiltration, conveyance losses within municipal water and wastewater systems, and closure of local water supplies derived from groundwater are examples of factors that may increase groundwater discharge. Climate variability and change may compound the implications of human activities relative to groundwater recharge, flow, and discharge.

Management Implications

Groundwater has important societal and ecological functions across the Great Lakes basin. Groundwater is typically a high quality water supply that is used by a significant portion of the population, particularly in rural areas where it is often the only available source of water. Groundwater discharge to rivers, lakes, and wetlands is also critical to aquatic species and habitat and to in-stream water quantity and quality. These functions are concurrent and occasionally conflicting. Pressures such as urban development and water use, in combination with the potential for climate impacts and further contamination of the resource, may increase the frequency and severity of these conflicts. In the absence of systematic accounting of groundwater supplies, use, and dependencies; it is the ecological function of groundwater that is most likely to be compromised.

Managing the water quality of the Great Lakes requires an understanding of water quantity and quality within the inland portion of the basin, and this understanding requires recognition of the relative contributions of surface runoff and groundwater discharge to stream flow. The results described in this report indicate the significant contribution of groundwater discharge to flow within the tributaries of the Great Lakes. The extent of this contribution has tangible management implications. There is considerable variability in groundwater recharge, flow, and discharge that must be reflected in the land and water management practices that are applied across the basin. The dynamics of groundwater flow and transport are different than those of surface water flow.

Groundwater discharge responds more slowly to climate and maintains stream flow during periods of reduced water availability; however, this capacity is known to be both variable and finite. Contaminants that are transported by groundwater may be in contact with geologic materials for years, decades, and perhaps even centuries or millennia. As a result, there may be considerable opportunity for attenuation of contamination prior to discharge. However, the lengthy residence times of groundwater flow also limit opportunities for the removal of contaminants, in general, and non-point source contaminants, in particular.

Comments from the author(s)

The indicated status and trend are estimates that the authors consider to be a broadly held opinion of water resource specialists within the Great Lakes basin. Further research and analysis is required to confirm these estimates and to determine conditions on a lake by lake basis.

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Brian Neff, U.S. Geological Survey; and
Marc Hinton, Geological Survey of Canada.
Contributors: Lori Fuller, U.S. Geological Survey and
Jim Nicholas, U.S. Geological Survey.

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List of Figures

Figure 10. Comparison of the values of base flow index calculated using the PART method of hydrograph separation to the values calculated using the UKIH method.
Source: Environment Canada and the U.S. Geological Survey

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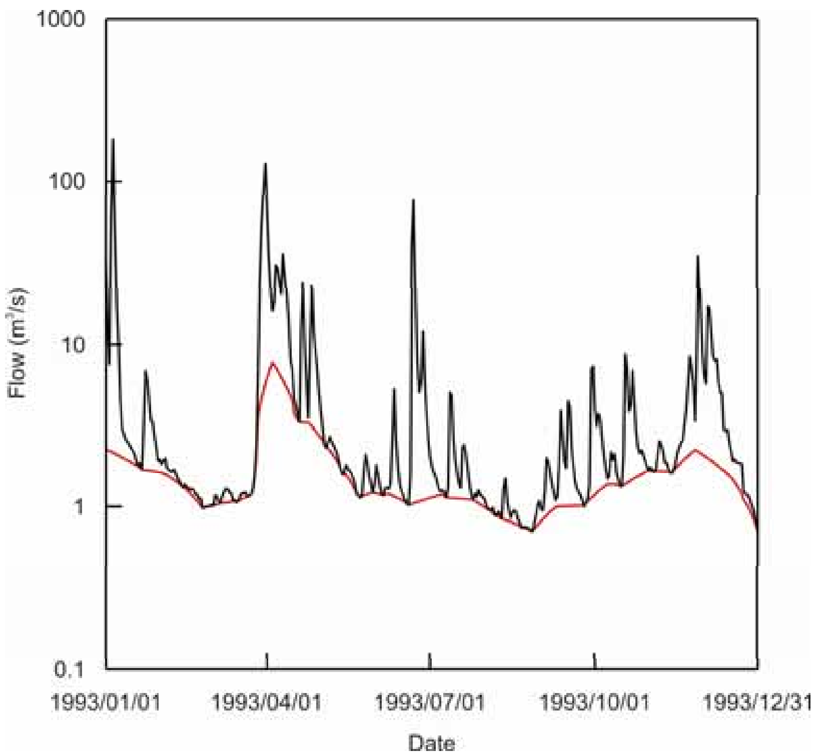

Figure 1. Hydrograph of observed total stream flow (black) and calculated base flow (red) for the Nith River at New Hamburg during 1993.
Source: Environment Canada and the U.S. Geological Survey

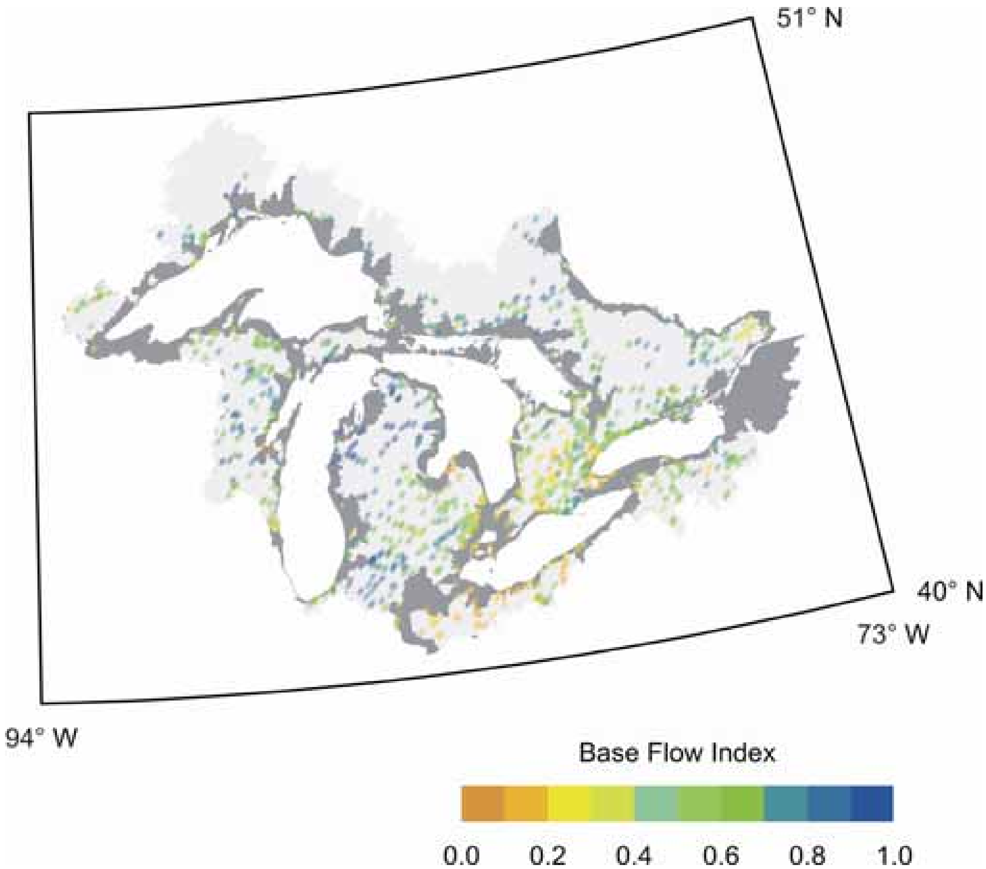

Figure 2. Distribution of the calculated values of base flow index relative to the gauged (light grey) and ungauged (dark grey) portions of the Great Lakes basin.
Source: Environment Canada and the U.S. Geological Survey

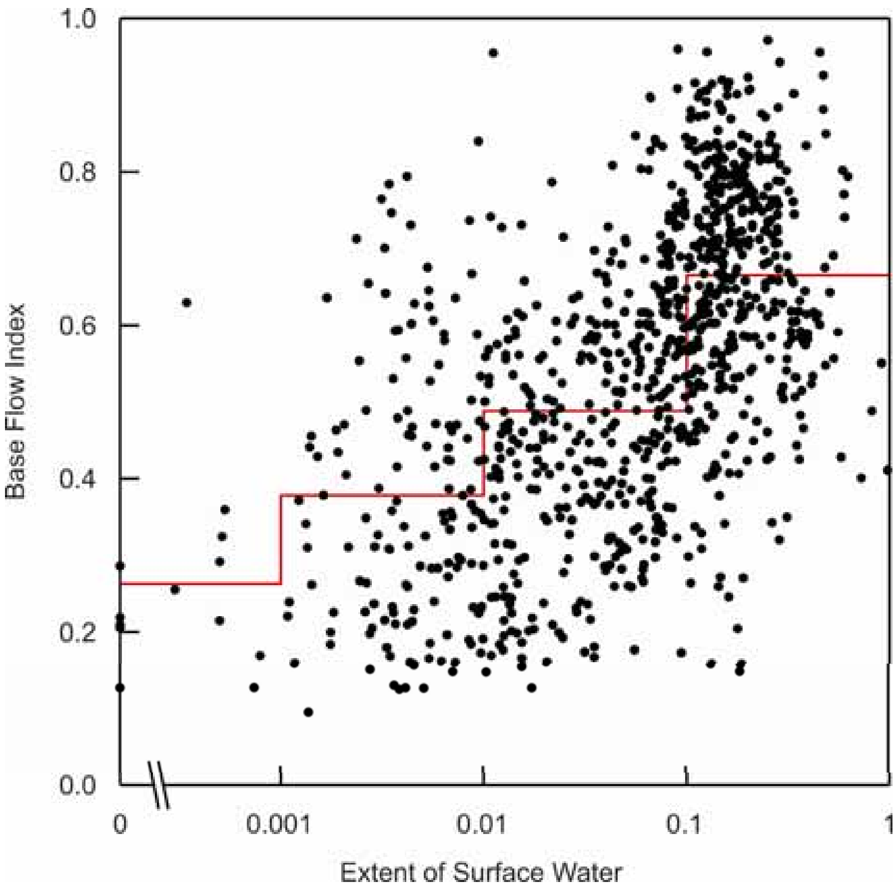

Figure 3. Comparison of the calculated values of base flow index to the corresponding extents of surface water. The step plot (red) indicates the averages of the values of base flow index within the four intervals of the extent of surface water.
Source: Environment Canada and the U.S. Geological Survey

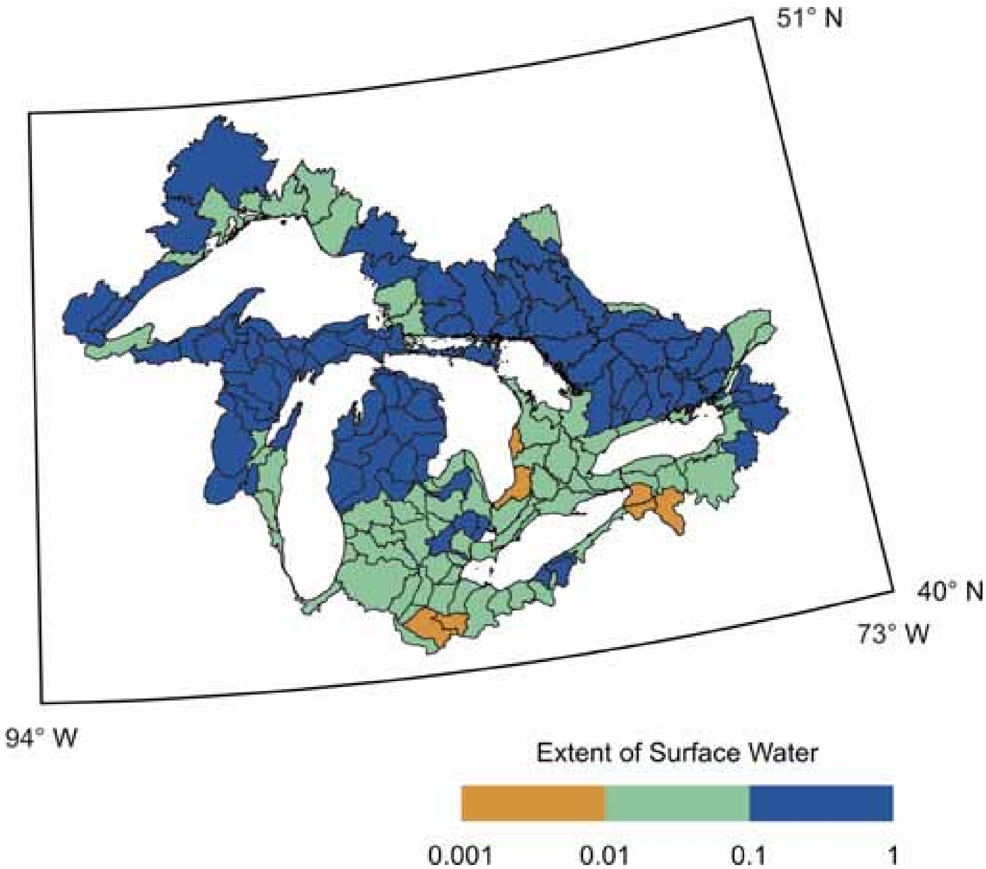

Figure 4. Distribution of the extents of surface water for the ungauged watersheds.
Source: Environment Canada and the U.S. Geological Survey

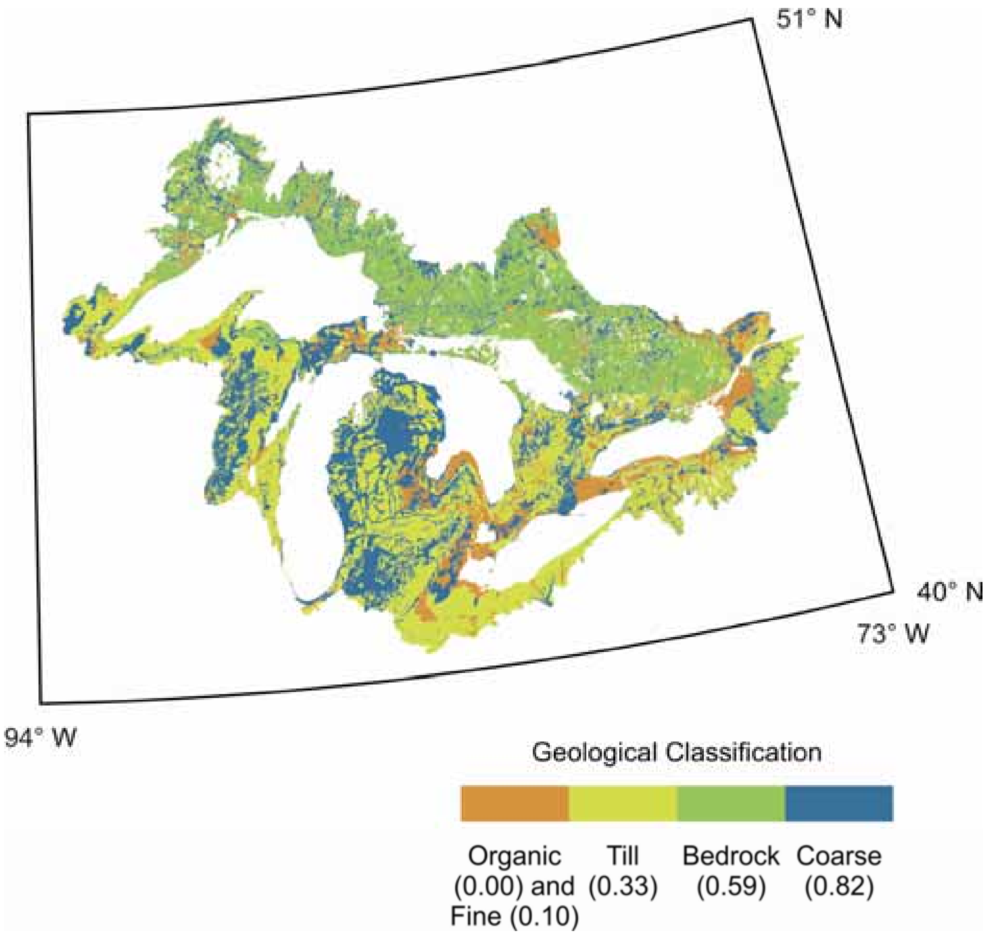

Figure 5. Distribution of the geological classifications. The classifications are shaded using the estimated values of the geological component of base flow index shown in parentheses.
Source: Environment Canada and the U.S. Geological Survey

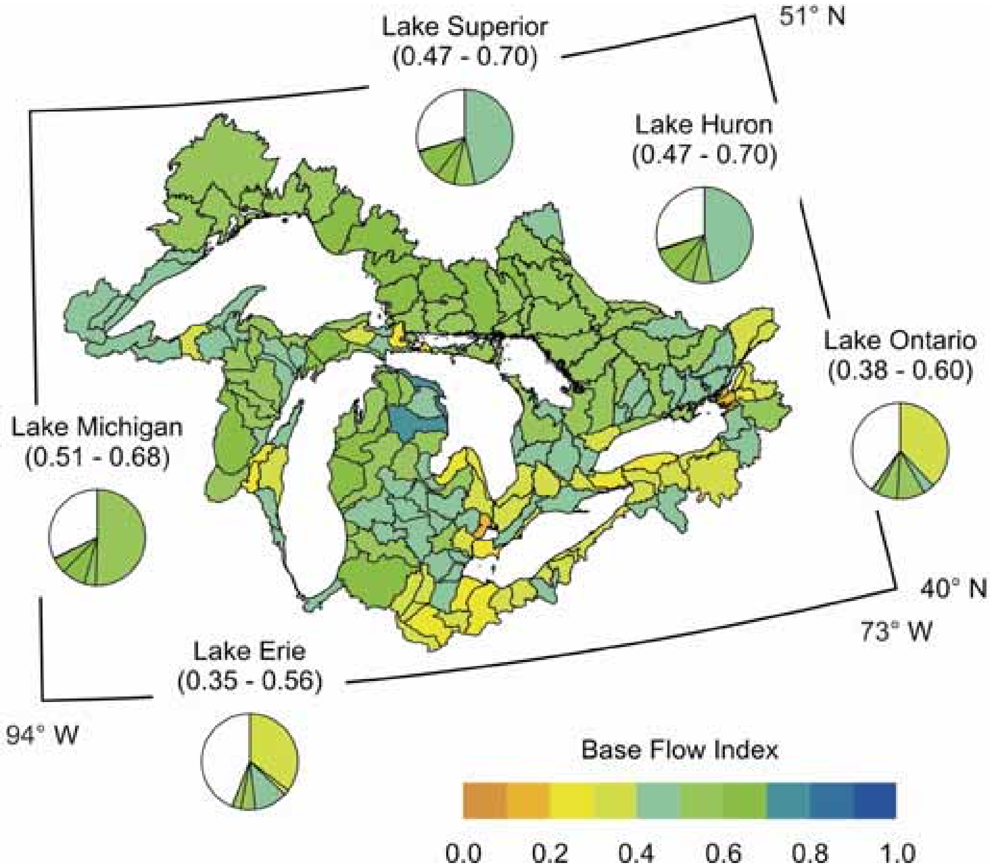

Figure 6. Distribution of the estimated values of the geological component of base flow index for the ungauged watersheds. The pie charts indicate the estimated values of the geological component of base flow index for the Great Lakes sub-basins corresponding to the six methods of hydrograph separation. The charts are shaded using the six values of base flow index and the numbers in parentheses are the range of the values.
Source: Environment Canada and the U.S. Geological Survey

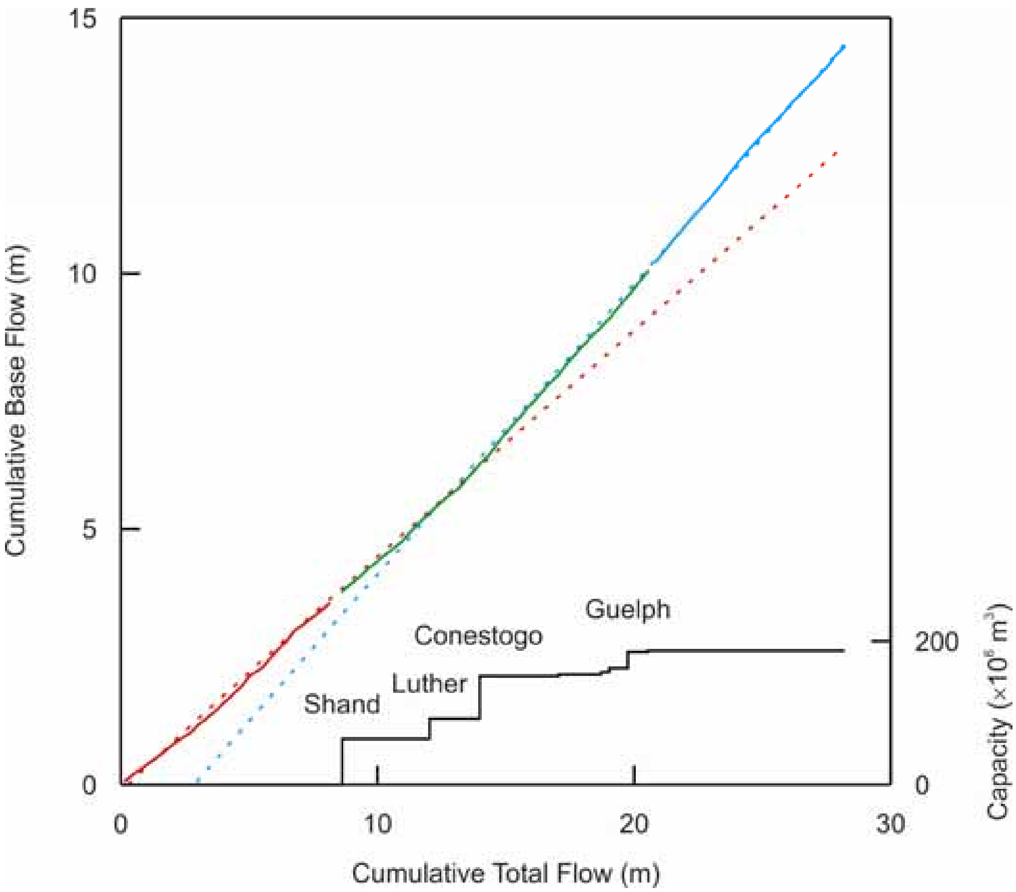

Figure 7. Cumulative base flow as a function of cumulative total flow for the Grand River at Galt prior to (red), during (green), and following (blue) the construction of the reservoirs that are located upstream of the stream flow gauge. The step plot indicates the cumulative storage capacity of the reservoirs where the construction of the largest four reservoirs is labeled. The dashed red and blue lines indicate uniform accumulation of flow based on data prior to and following, respectively, the construction of the reservoirs.
Source: Environment Canada and the U.S. Geological Survey

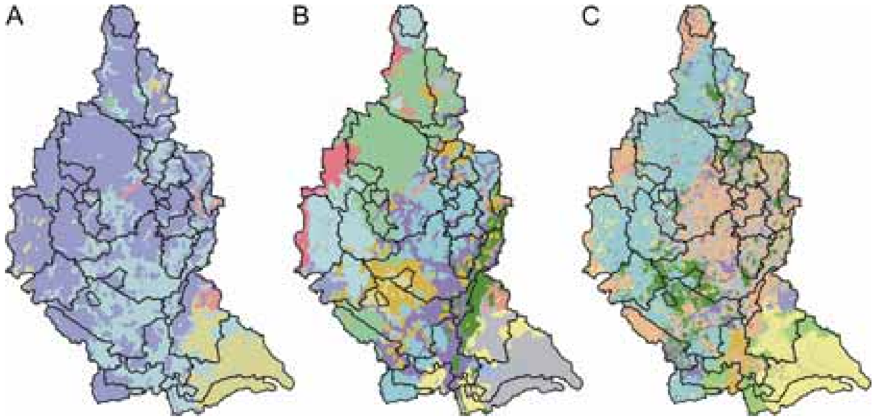

Figure 8. Geology of the gauged portion of the Grand River watershed based on the classification (A) and full resolution (B) of the 1:1,000,000 scale Quaternary geology mapping and the full resolution of the 1:50,000 scale Quaternary geology mapping (C) where random colours are used to differentiate the various geological classifications and units.
Source: Environment Canada and the U.S. Geological Survey

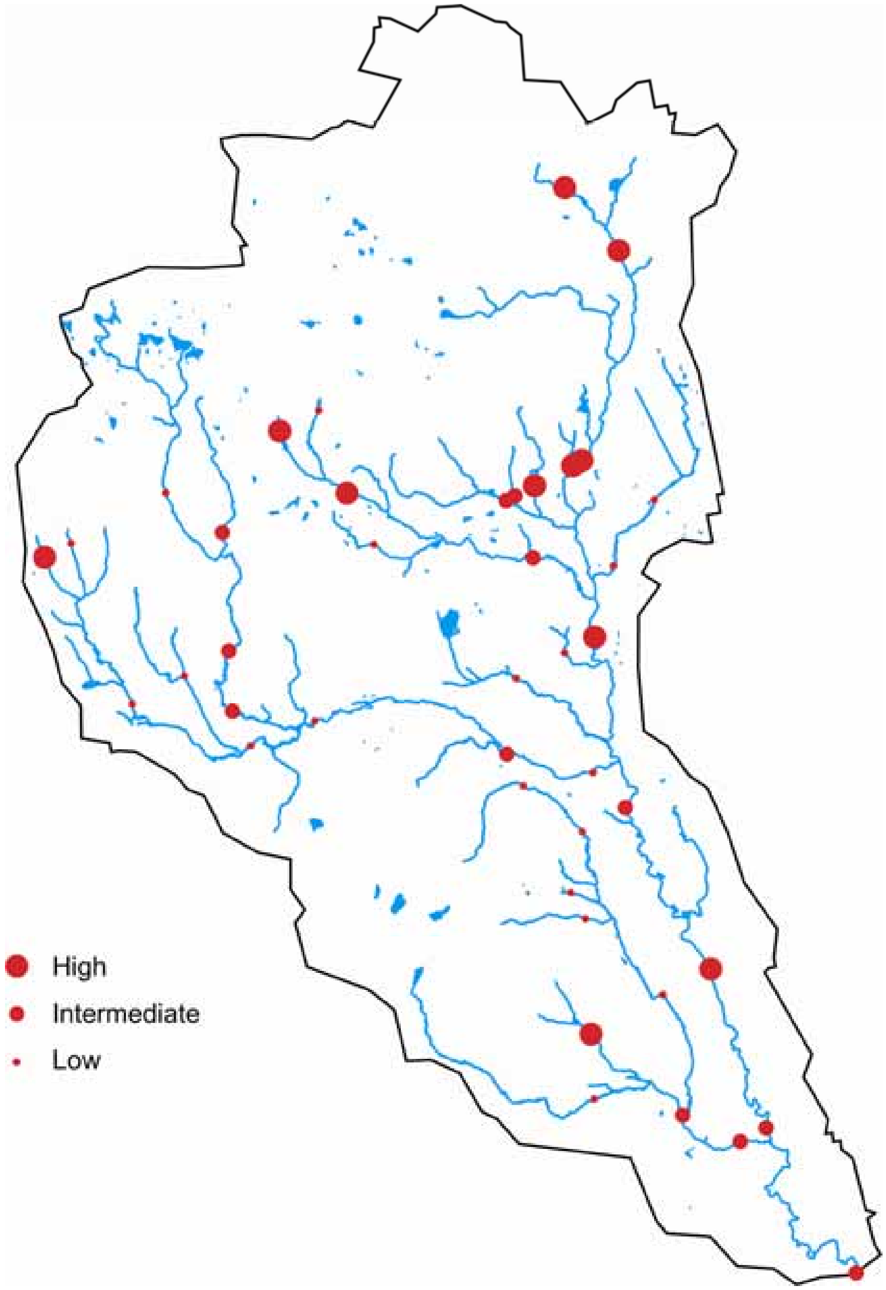

Figure 9. Distribution of the standardized values of low flow within the watershed of Duffins Creek above Pickering.
Source: Environment Canada and the U.S. Geological Survey, Geological Survey of Canada, and Ontario Ministry of Natural Resources

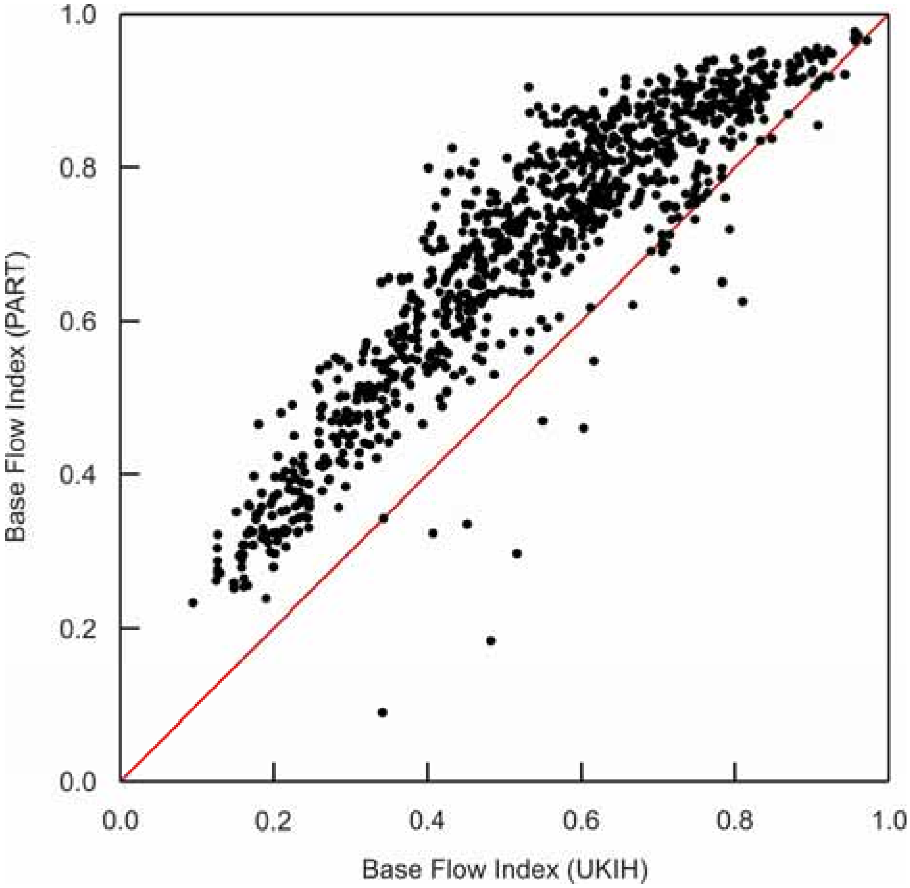

Figure 10. Comparison of the values of base flow index calculated using the PART method of hydrograph separation to the values calculated using the UKIH method.
Source: Environment Canada and the U.S. Geological Survey

Groundwater Dependant Plant and Animal Communities

Indicator #7103

Assessment: Not Assessed

Note: This indicator report uses data from the Grand River watershed only and may not be representative of groundwater conditions throughout the Great Lakes basin. Additionally, there is insufficient biological and physical hydrological data for most of the streams in the Grand River watershed to report on many of the selected species reliant on groundwater discharge, hence this discussion focuses on brook trout (*Salvelinus fontinalis*) as an indicator of groundwater discharge.

Purpose

- To measure the abundance and diversity as well as presence or absence of native invertebrates, fish, plant and wildlife (including cool-water adapted frogs and salamanders) communities that are dependent on groundwater discharges to aquatic habitat;
- To identify and understand any deterioration of water quality for animals and humans, as well as changes in the productive capacity of flora and fauna dependant on groundwater resources;
- To use biological communities to assess locations of groundwater intrusions; and
- To infer certain chemical and physical properties of groundwater, including changes in patterns of seasonal flow.

Ecosystem Objective

The goal for this indicator is to ensure that plant and animal communities function at or near maximum potential and that populations are not significantly compromised due to anthropogenic factors.

State of the Ecosystem

Background

The integrity of larger water bodies can be linked to biological, chemical and physical integrity of the smaller watercourses that feed them. Many of these small watercourses are fed by groundwater. As a result, groundwater discharge to surface waters becomes cumulatively important when considering the quality of water entering the Great Lakes. The identification of groundwater fed streams and rivers will provide useful information for the development of watershed management plans that seek to protect these sensitive watercourses.

Human activities can change the hydrological processes in a watershed resulting in changes to recharge rates of aquifers and discharges rates to streams and wetlands. This indicator should serve to identify organisms at risk because of human activities can be used to quantify trends in communities over time.

Status of Groundwater Dependent Plant and Animal Communities in the Grand River Watershed

The surficial geology of the Grand River watershed is generally divided into three distinct regions; the northern till plain, central moraines with large sand and gravel deposits, and the southern clay plain (Figure 1). These surficial overburden deposits are underlain by thick sequences of fractured carbonate rock (predominantly dolostone).

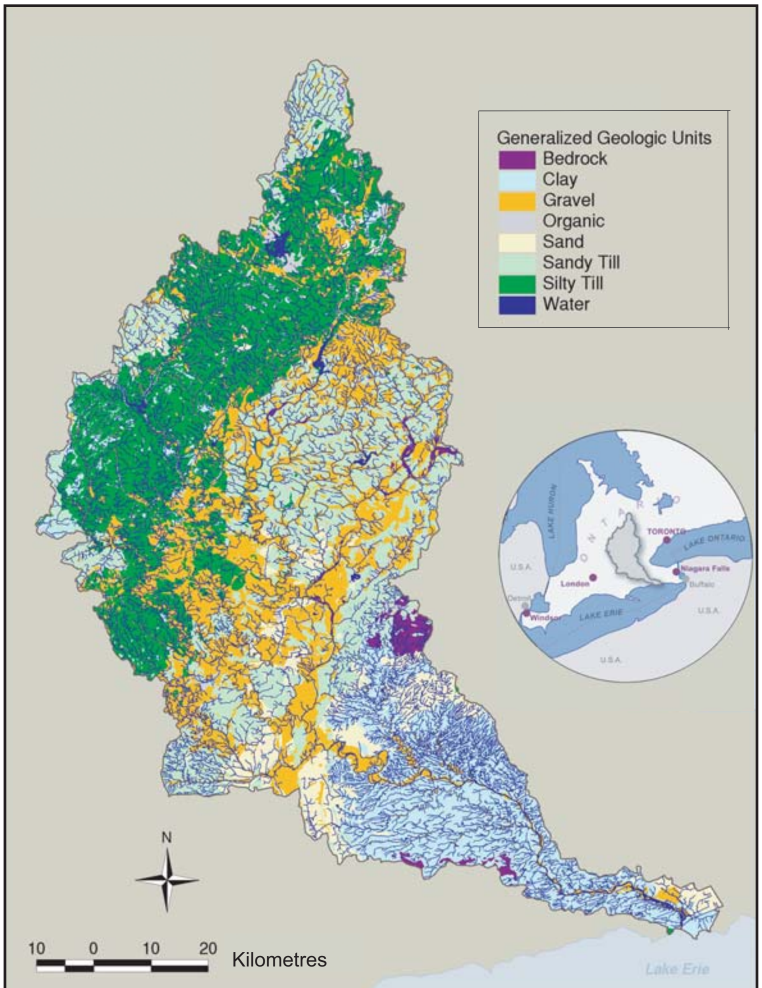

Figure 1. Surficial geology of the Grand River watershed.
Source: Grand River Conservation Authority

The Grand River and its tributaries form a stream network housing approximately 11,329 km of stream habitat. The Ontario Ministry of Natural Resources (OMNR) has classified many of Ontario's streams based on habitat type. While many streams and rivers in the Grand River watershed remain unclassified, the MNR database currently available through the Natural Resources and Values Information System (NRVIS) has documented and classified about 22% of the watershed's streams (Figure 2). Approximately 19% of the classified streams are cold-water habitat and therefore dependent on groundwater discharge. An additional 16% of the classified streams are considered potential cold-water habitat. The remaining 65% of classified streams are warm-water habitat.

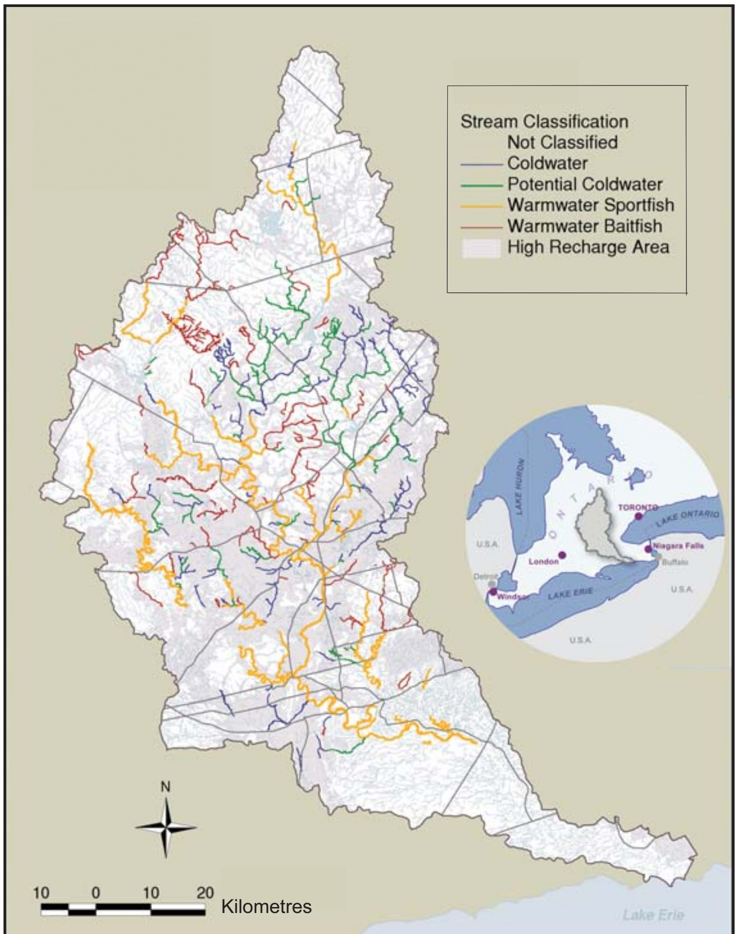

Figure 2. Streams of the Grand River watershed.
Source: Grand River Conservation Authority

A map of potential groundwater discharge areas was created for the Grand River watershed by examining the relationship between the water table and ground surface (Figure 3). This map indicates areas in the watershed where water well records indicate that the water table could potentially be higher than the ground surface. In areas where this is the case, there is a strong tendency toward discharge of groundwater to land, creating cold-water habitats. Groundwater discharge appears to be geologically controlled with most potential discharge areas noted associated with the sands and gravels in the central moraine areas and little discharge in the northern till plain and southern clay plain. The map suggests that some of the unclassified streams in Figure 2 may be potential cold-water streams, particularly in the central portion of the watershed where geological conditions are favourable to groundwater discharge.

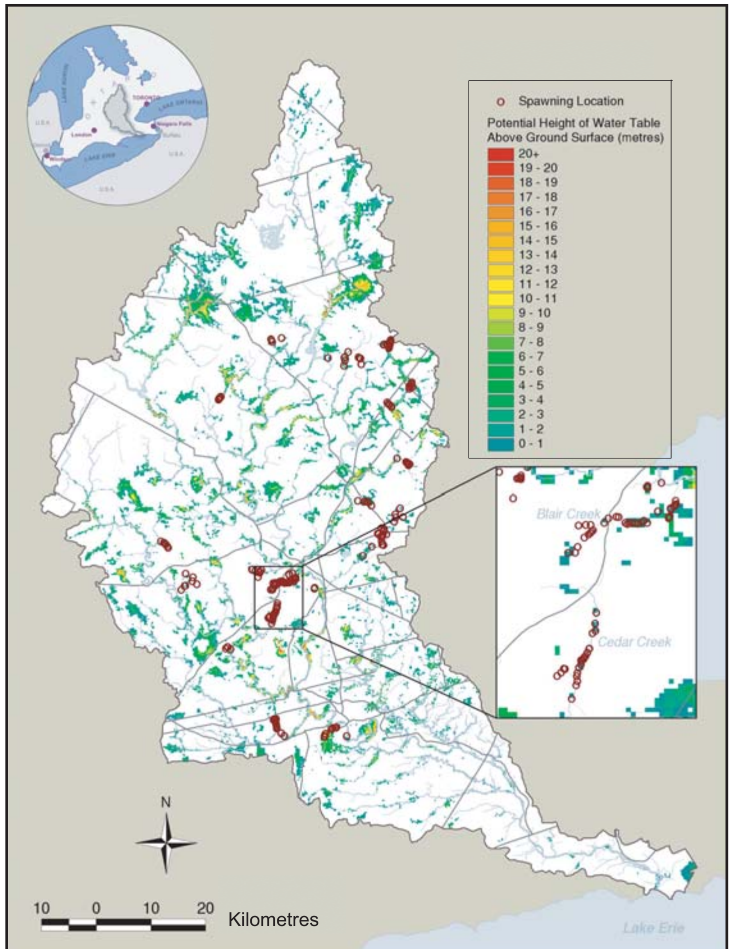

Figure 3. Map of potential discharge areas in the Grand River watershed.
Source: Grand River Conservation Authority

Brook trout is a freshwater fish species native to eastern Canada. The survival and success of brook trout is closely tied to cold groundwater discharges in streams used for spawning. Specifically, brook trout require inputs of cold, clean water to successfully reproduce. As a result, nests or redds are usually located in substrate where groundwater is upwelling into surface water. A significant spawning population of adult brook trout generally indicates a constant source of cool, good quality groundwater.

Locations of observed brook trout redds are shown on Figure 3. The data shown are a compilation of several surveys carried out on selected streams in 1988 and 1989. Additional data from several sporadic surveys carried out in the 1990s are also included. These redds may represent single or multiple nests from brook trout spawning activity. The results of these surveys illustrate that there are significant high quality habitats in several of the subwatersheds in the basin.

Cedar Creek is a tributary of the Nith River in the central portion of the watershed. It has been described as containing some of the best brook trout habitat in the watershed. Salmonoid spawning surveys for brook trout were carried out over similar stretches of the creek in 1989 and 2003 (Figure 4). In 1989 a total redd count of 53 (over 4.2 km) was surveyed while in 2003 the total redd count was 59 (over 5.4 km). In both surveys, many of the redds counted were multiple redds meaning several fish had spawned at the same locations. Redd densities in 1989 and 2003 were 12.6 redds/km and 10.9 redds/km respectively. From Figure 4 it appears that in 2003 brook trout were actively spawning in Cedar Creek in mainly the same locations as in 1989. While redd density in Cedar Creek has decreased slightly, the similar survey results suggest that groundwater discharge has remained fairly constant and reductions in discharge have not significantly affected aquatic habitat.

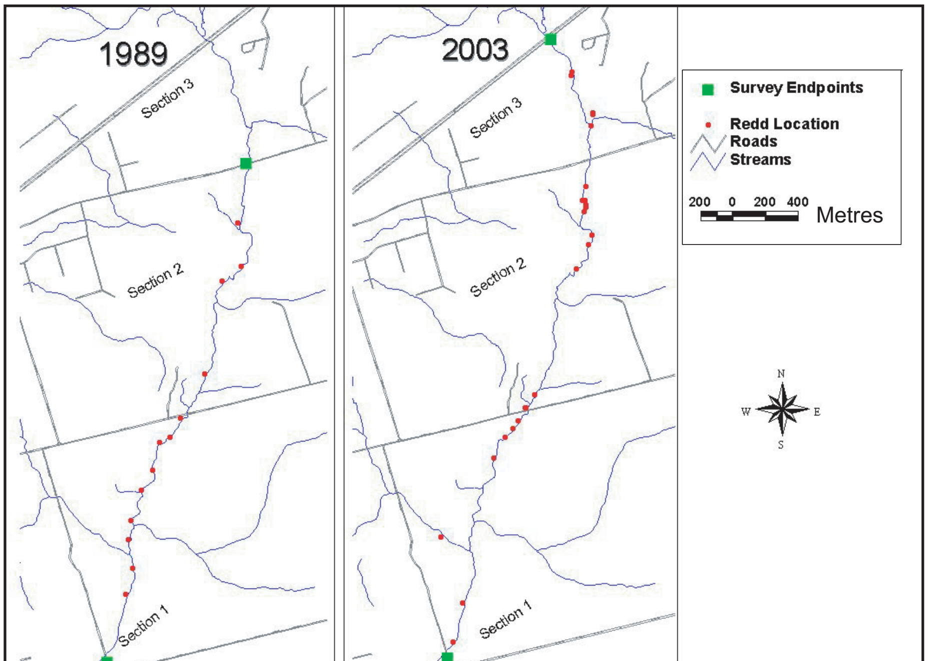

Figure 4. Results of brook trout spawning surveys carried out in the Cedar Creek subwatershed in 1989 and 2003.
Source: Grand River Conservation Authority

Pressures

The removal of groundwater from the subsurface through pumping at wells reduces the amount of groundwater discharging into surface water bodies. Increasing impervious surfaces reduces the amount of water that can infiltrate into the ground and also ultimately reduces groundwater discharge into surface water bodies. Additionally, reducing the depth to the water table from ground surface will decrease the geological protection afforded groundwater supplies and may increase the temperature of groundwater. Higher temperatures can reduce the moderating effect groundwater provides to aquatic stream habitat. At local scales the creation of surface water bodies through mining or excavation of aggregate or rock may change groundwater flow patterns, which in turn might decrease groundwater discharge to sensitive habitats.

In the Grand River watershed, groundwater is used by about 80% of the watershed's residents as their primary water supply. Additionally, numerous industrial and agricultural users also use groundwater for their operations. Growing urban communities will put pressure on the resource and if not managed properly will lead to decreases in groundwater discharge to streams. Development in some areas can also lead to decreased areas available for precipitation to percolate through the ground and recharge groundwater supplies.

Management Implications

Ensuring that an adequate supply of cold groundwater continues to discharge into streams requires protecting groundwater recharge areas and ensuring that groundwater withdrawals are undertaken at sustainable rates. Additionally, an adequate supply of groundwater for habitat purposes does not only refer to the quantity of discharge but also to the chemical quality, temperature and spatial location of that discharge. As a result, protecting groundwater resources is complicated and generally requires multi-faceted strategies including regulation, voluntary adoption of best management practices and public education.

Acknowledgments

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Authors' Commentary

This report has focused on only one species dependent on groundwater discharge for its habitat. The presence or absence of other species should be investigated through systematic field studies.

Last Updated

State of the Great Lakes 2005

Area, Quality and Protection of Special Lakeshore Communities - Alvars

Indicator #8129 (Alvars)

Assessment: Mixed, Trend Not Assessed

Purpose

- To assess the status of Great Lakes alvars (including changes in area and quality), one of the 12 special lakeshore communities identified within the nearshore terrestrial area;
- To infer the success of management activities; and
- To focus future conservation efforts toward the most ecologically significant alvar habitats in the Great Lakes.

Ecosystem Objective

The objective is the preservation of the area and quality of Great Lakes alvars, individually and as an ecologically important system, for the maintenance of biodiversity and the protection of rare species. This indicator supports Annex 2 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Background

Alvar communities are naturally open habitats occurring on flat limestone bedrock. They have a distinctive set of plant species and vegetative associations, and include many species of plants, molluscs, and invertebrates that are rare elsewhere in the basin. All 15 types of alvars and associated habitats are globally imperiled or rare.

A four-year study of Great Lakes alvars completed in 1998 (the International Alvar Conservation Initiative-IACI) evaluated conservation targets for alvar communities, and concluded that essentially all of the existing viable occurrences should be maintained, since all types are below the minimum threshold of 30-60 viable examples. As well as conserving these ecologically distinct communities, this target would protect populations of dozens of globally significant and disjunct species. A few species, such as lakeside daisy (*Hymenoxis herbacea*) and the beetle *Chlaenius p. purpuricollis*, have nearly all of their global occurrences within Great Lakes alvar sites.

Status of Great Lakes Alvars

Alvar habitats have likely always been sparsely distributed, but more than 90% of their original extent has been destroyed or substantially degraded by agriculture and other human uses. Approximately 64% of the remaining alvar area occurs within Ontario, with about 16% in New York State, 15% in Michigan, 4% in Ohio, and smaller areas in Wisconsin and Quebec. Data from the IACI and state/provincial alvar studies were screened and updated to identify viable community occurrences. Just over two-thirds of known Great Lakes alvars occur close to the shoreline, with all or a substantial portion of their area within one kilometre of the shore.

	Total in Basin	Nearshore
No. of alvar sites	82	52
No. of community occurences	204	138
Alvar area (ha)	11,523	8,097

Table 1. Number of alvar sites/communities found nearshore and total in the basin.
Source: Ron Reid, Bobolink Enterprises

Typically, several different community types occur within each alvar site. Among the 15 community types documented, six types show a strong association (over 80% of their area) with nearshore settings. Four types have less than half of their occurrences in nearshore settings.

The current status of all nearshore alvar communities was evaluated by considering current land ownership and the type and severity of threats to their integrity. As shown in Figure 1, less than one-fifth of the nearshore alvar area is currently fully protected, while over three-fifths is at high risk.

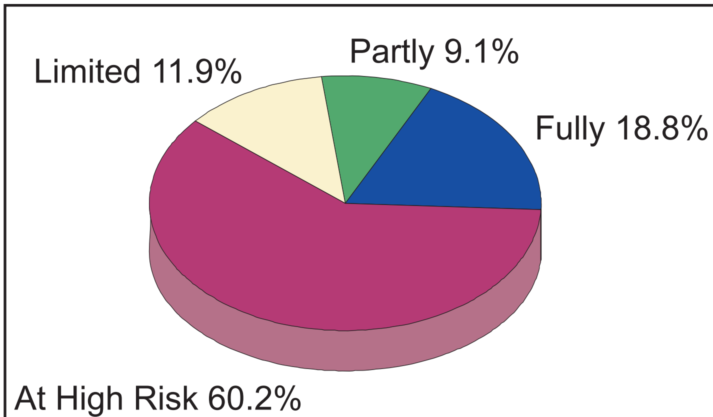

Figure 1. Protection status of nearshore alvar area (2000).
Source: Ron Reid, Bobolink Enterprises

The degree of protection for nearshore alvar communities varies considerably among jurisdictions. For example, Michigan has 66% of its nearshore alvar area in the Fully Protected category, while Ontario has only 7%. In part, this is a reflection of the much larger total shoreline area in Ontario, as shown in Figure 2. (Other states have too few nearshore sites to allow comparison).

Each location of an alvar community or rare species has been documented as an "element occurrence" or EO. Each alvar com-

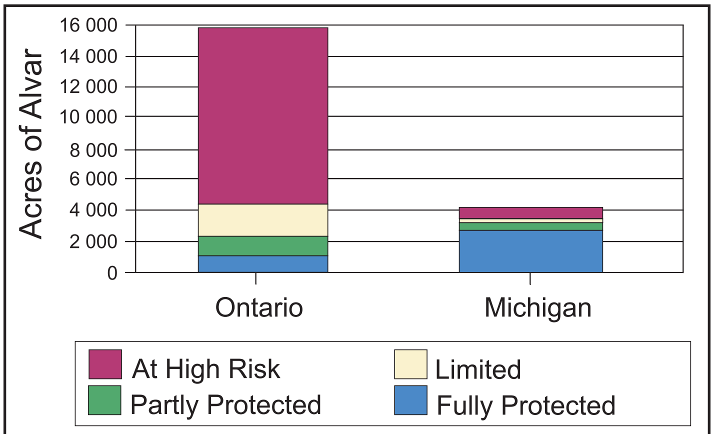

Figure 2. Comparison of the protection status of nearshore alvars (in acres) for Ontario and Michigan.
Source: Ron Reid, Bobolink Enterprises

munity occurrence has been assigned an "EO rank" to reflect its relative quality and condition ("A" for excellent to "D" for poor). A and B-ranks are considered viable, while C-ranks are marginal and a D ranked occurrence is not expected to survive even with appropriate management efforts. As shown in Figure 3, protection efforts to secure alvars have clearly focused on the best quality sites.

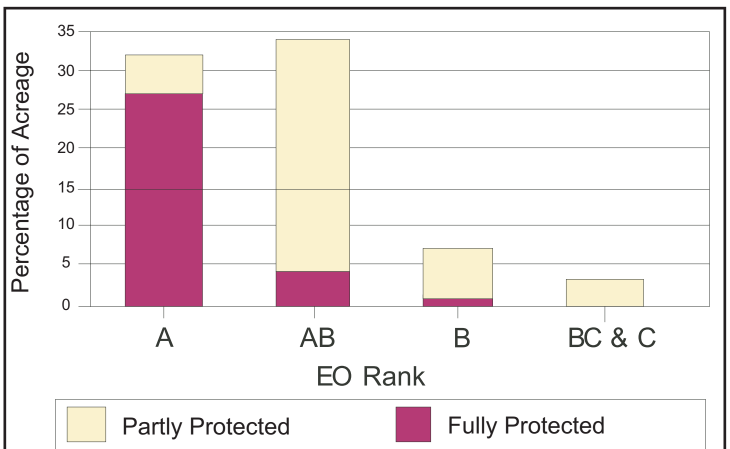

Figure 3. Protection of high quality alvars. EO Rank = Element Occurrence (A is excellent, B is good and C is marginal).
Source: Ron Reid, Bobolink Enterprises

Documentation of the extent and quality of alvars through the IACI has been a major step forward, and has stimulated much greater public awareness and conservation activity for these habitats. Over the past two years, a total of 10 securement projects have resulted in protection of at least 2140.6 ha of alvars across the Great Lakes basin, with 1353.5 ha of that within the nearshore area. Most of the secured nearshore area is through land acquisition, but 22.7 ha on Pelee Island (ON) are through a conservation easement, and 0.6 ha on Kelleys Island (OH) are through state dedication of a nature reserve. These projects have increased the area of protected alvar dramatically in a short time.

Pressures

Nearshore alvar communities are most frequently threatened by habitat fragmentation and loss, trails and off-road vehicles, resource extraction uses such as quarrying or logging, and adjacent land uses such as residential subdivisions. Less frequent threats include grazing or deer browsing, plant collecting for bonsai or other hobbies, and invasion by non-native plants such as European buckthorn and dog-strangling vine.

Acknowledgments

Authors: Ron Reid, Bobolink Enterprises, Washago, ON; and Heather Potter, The Nature Conservancy, Chicago, IL.

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Authors' Commentary

Because of the large number of significant alvar communities at risk, particularly in Ontario, their status should be closely watched to ensure that they are not lost. Major binational projects hold great promise for further progress, since alvars are a Great Lakes resource, but most of the unprotected area is within Ontario. Projects could be usefully modeled after the 1999 Manitoulin Island (ON) acquisition of 6880 ha through a cooperative project of The Nature Conservancy of Canada, The Nature Conservancy, Federation of Ontario Naturalists, and Ontario Ministry of Natural Resources.

Last Updated

State of the Great Lakes 2001

Area, Quality and Protection of Special Lakeshore Communities - Cobble Beaches

Indicator #8129 (Cobble Beaches)

Assessment: Mixed, Deteriorating

Purpose

- To assess the status of cobble beaches, one of the 12 special shoreline communities identified within the nearshore terrestrial area. To assess the changes in area and quality of Great Lakes cobble beaches;
- To infer the success of management activities; and
- To focus future conservation efforts toward the most ecologically significant cobble beach habitats in the Great Lakes.

Ecosystem Objective

The objective is the preservation of the area and quality of Great Lakes cobble beaches, individually and as an ecologically important system, for the maintenance of biodiversity and the protection of rare species. This indicator supports Annex 2 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Background

Cobble beaches are shaped by wave and ice erosion. They are home to a variety of plant species, several of which are threatened or endangered provincially/statewide, globally, or both making them one of the most biodiverse terrestrial communities along the Great Lakes shoreline. Cobble beaches serve as seasonal spawning and migration areas for fish as well as nesting areas for the piping plover, a species listed in the U.S. as endangered.

Status of Cobble Beaches

Cobble beaches have always been a part of the Great Lakes shoreline. The number and area of these beaches, however, is decreasing due to shoreline development. In fact, cobble shorelines are becoming so scarce that they are considered globally rare.

Lake Superior has the most cobble shoreline of all the Great Lakes with 958 km of cobble beaches (Figure 1); 541 km on the Canadian side and 417 km on the U.S. side. This constitutes 20% of the whole Lake Superior shoreline (11.3% on the Canadian side and 8.7% on the U.S. side).

Lake Huron has the 2nd most cobble shoreline with approximately 483 km of cobble shoreline; 330 km on the Canadian side and 153 km on the U.S. side. Most of the cobble beaches are found along the shoreline of the Georgian Bay (Figure 2). This constitutes approximately 9% of the whole Lake Huron shoreline (6.1% on the Canadian side and 2.8% on the U.S. side).

Approximately 164 km of the Lake Michigan shoreline is cobble, representing 6.1% of its shoreline. Most of these beaches are located at the northern end of the lake in the state of Michigan (Figure 3).

Lake Ontario has very little cobble shoreline of about 35 km, representing only 3% of its shoreline (Figure 4).

Figure 1. Cobble beaches along Lake Superior's shoreline (red = cobble beach locations).
Source: Lake Superior Binational Program, Lake Superior LaMP 2000, Environment Canada, and Dennis Albert

Figure 2. Cobble beaches along Lake Huron's shoreline (red = cobble beach locations).
Source: Environment Canada

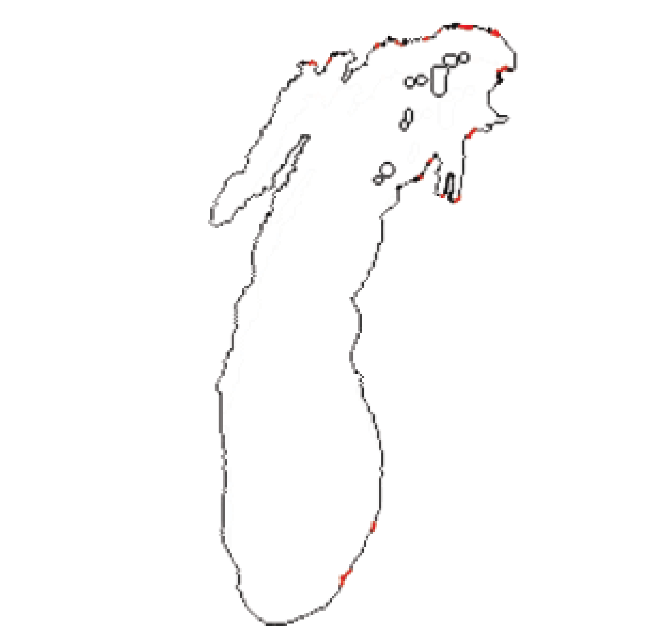

Figure 3. Cobble beaches along Lake Michigan's shoreline (red = cobble beach locations).
Source: Albert 1994a, Humphrys *et al.* 1958

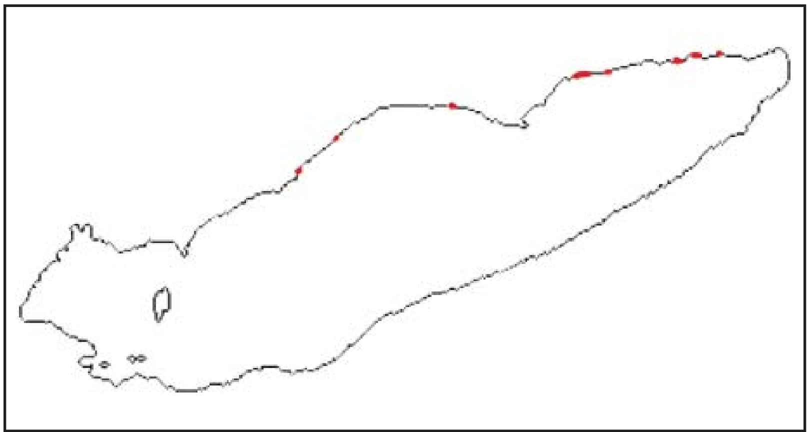

Figure 5. Cobble beaches along Lake Erie's shoreline (red = cobble beach locations).
Source: Environment Canada

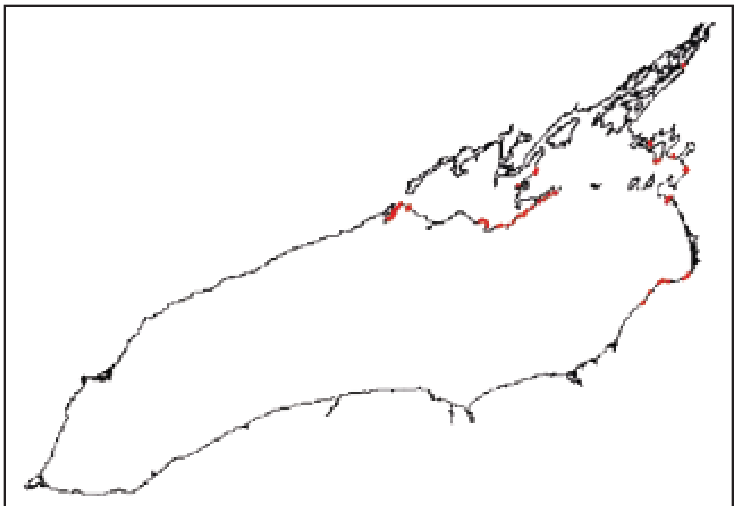

Figure 4. Cobble beaches along Lake Ontario's shoreline (red = cobble beach locations).
Source: International Joint Commission (IJC) and Christian J. Stewart

Lake Erie has the smallest amount of cobble shoreline of all the Great Lakes with only 26 km of cobble shore. This small area represents approximately 1.9% of the lake's shoreline (Figure 5).

While the cobble beaches themselves are scarce, they do have a wide variety of vegetation associated with them, and they serve as home to plants that are endemic to the Great Lakes shoreline. Lake Superior's large cobble shoreline provides for several rare plant species (Table 1) some of which include the Lake Huron tansy and redroot. It is also home to the endangered heart-leaved plantain, which is protected under the Ontario Endangered Species Act.

Lake Superior	
Common Name	**Scientific Name**
Bulrush sedge	*Carex scirpoidea*
Great northern aster	*Aster modestus*
Northern reedgrass	*Calamagrostis lacustris*
Purple clematis	*Clematis occidentalis*
Northern grass of Parnassus	*Parnassia palustris*
Mountain goldenrod	*Solidago decumbens*
Narrow-leafed reedgrass	*Calamagrostis stricta*
Downy oat-grass	*Trisetum spicatum*
Pale Indian paintbrush	*Castilleja septentrionalis*
Butterwort	*Pinguicula vulgaris*
Pearlwort	*Sagina nodosa*
Calypso orchid	*Calypsa bulbosa*
Lake Huron tansy	*Tanacetum huronense*
Redroot	*Lachnanthes caroliana*
Heart-leaved plantain	*Plantago cordata*

Table 1. Rare plant species on Lake Superior's cobble shoreline.
Source: Lake Superior LaMP, 2000

Lake Michigan and Lake Huron's cobble shorelines are home to Houghton's goldenrod and the dwarf lake iris, both of which are endemic to the Great Lakes shoreline (Table 2, Table 3). Some other rare species on the Lake Michigan shoreline include the Lake Huron tansy and beauty sedge (Table 2).

Not many studies have been conducted on the cobble shorelines of Lake Ontario and Lake Erie because these areas are so small. The report author was unable to find any information about the vegetation that grows there.

Lake Michigan	
Common Name	**Scientific Name**
Dwarf lake iris	*Iris lacustris*
Houghton's goldenrod	*Solidago houghtonii*
Slender cliff-brake	*Cryptogramma stelleri*
Lake Huron tansy	*Tanacetum huronense*
Beauty sedge	*Carex concinna*
Richardson's sedge	*Carex richardsonii*

Table 2. Rare plant species along Lake Michigan's cobble shoreline.
Source: Dennis Albert

Lake Huron	
Common Name	**Scientific Name**
Dwarf lake iris	*Iris lacustris*
Houghton's goldenrod	*Solidago houghtonii*

Table 3. Rare plant species along Lake Huron's cobble shoreline.
Source: Environment Canada

Pressures

Cobble beaches are most frequently threatened and lost by shoreline development. Homes built along the shorelines of the Great Lakes cause the number of cobble beaches to become limited. Along with the development of homes also comes increased human activity along the shoreline resulting in damage to rare plants in the surrounding area and ultimately a loss of terrestrial biodiversity on the cobble beaches.

Acknowledgments

Author: Jacqueline Adams, Environmental Careers Organization, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office.

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Authors' Commentary

Not much research has been conducted on cobble beach communities; therefore, no baseline data have been set. A closer look into the percentage of cobble beaches that already have homes on them or are slated for development would yield a more accurate direction in which the beaches are headed. Also, a look at the percentage of these beaches that are in protected areas would provide valuable information. Projects similar to Dennis Albert's *Bedrock Shoreline Surveys of the Keweenaw Peninsula and Drummond Island in Michigan's Upper Peninsula* (1994) for the Michigan Natural Features Inventory, as well as the International Joint Commission's *Classification of Shore Units Coastal Working Group*: *Lake Ontario and Upper St. Lawrence River* (2002), would be very useful in determining exactly where the remaining cobble beaches are located and what is growing and living within them.

Last Updated

State of the Great Lakes 2005

Extent, Condition and Conservation Management of Great Lakes Islands
Indicator #8129

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Primary Factors Determining Status and Trend: **The Framework for Binational Conservation of Great Lakes Islands will be completed in 2007. The following results reflect detailed analysis from Canadian islands and preliminary results from the US. This project has created the first detailed binational map Great Lakes islands. This includes the identification of 31,407 island polygons with a total coastline of 15,623 km.**

This project has established baseline information that will be used to assess future trends.

Lake-by-Lake Assessment

Lake Superior

Status: Good
Trend: Undetermined
Primary Factors Determining Status and Trend: Detailed analysis for Canada only. Total (Canada and US) of 2,591 island polygons. St. Mary's River has 630 island polygons.

Canadian islands in Lake Superior have the lowest threats score in the basin. A high proportion of these islands are within protected areas and conservation lands. Overall condition is good. These islands include a high number of disjunct plant species.

Lake Michigan

Status: Not Assessed
Trend: Undetermined
Primary Factors Determining Status and Trend: Detailed analysis not completed. Total of 329 island polygons.

Lake Huron

Status: Mixed
Trend: Undetermined
Primary Factors Determining Status and Trend: Detailed analysis for Canada only. Total (Canada and US) of 23,719 island polygons (includes Georgian Bay).

These islands tend to be more threatened in the south compared to the north. A large number of protected areas and conservation lands occur in the northern region. Southern regions are more developed, and under increasing pressures from development. These islands include high number of globally rare species and vegetation communities.

Lake Erie

Status:	Mixed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Detailed analysis for Canada only. Total (Canada and US) of 1,724 island polygons. Other island polygons with Lake St. Clair/ St. Clair River (339), Detroit River (61) and Niagara River (36). These islands include a mix of protected areas and private islands. Islands in the western Lake Erie basin have some of the highest biodiversity values of all Great Lakes islands.

Lake Ontario

Status:	Mixed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Detailed analysis for Canada only. Total (Canada and US) of 2,591 island polygons (including upper St. Lawrence River). Many of these islands have high threat index scores and a long history of recreational use. One of the highest building point counts. Few areas have been protected.

Purpose

•To assess the status of islands, one of the 12 special lakeshore communities identified within the nearshore terrestrial area.

Ecosystem Objective

To assess the changes in area and quality of Great Lakes islands individually, and as an ecologically important system; to infer the success of management activities; and to focus future conservation efforts toward the most ecologically significant island habitats in the Great Lakes.

State of the Ecosystem

Background

There are 31,407 islands that have been idnetified in the Great Lakes (Figure 1). The islands range in size from no bigger than a large boulder to the world's largest freshwater island, Manitoulin, and often form chains of islands known as archipelagos. Though not well known, the Great Lakes contain the world's largest freshwater island system, and are globally significant in terms of their biological diversity. Despite this, the state of our knowledge about them as a collection is quite poor.

By their very nature, islands are vulnerable and sensitive to change. Islands are exposed to the forces of erosion and accretion as water levels rise and fall. Islands are also exposed to weather events due to their 360-degree exposure to the elements across the open water. Isolated for perhaps tens of thousands of years from the mainland, islands in the past rarely gained new species, and some of their resident species evolved into endemics that differed from mainland varieties. This means that islands are especially vulnerable to the introduction of non-native species, and can only support a fraction of the number of species of a comparable mainland area.

Some of the Great Lakes islands are among the last remaining wildlands on Earth. Islands must be considered as a single irreplaceable resource and protected as a whole if the high value of this natural heritage is to be maintained. Islands play a particularly important role in the "storehouse" of Great Lakes coastal biodiversity. For example, Michigan's 600 Great Lakes islands contain one-tenth of the state's threatened, endangered, or rare species while representing only one-hundredth of the land area. All of Michigan's threatened, endangered, or rare coastal species occur at least in part on its islands. The natural features of particular importance on Great Lakes islands are colonial waterbirds, neartic-neotropical migrant songbirds, endemic plants, arctic disjuncts, endangered species, fish spawning and nursery use of associated shoals and reefs and other aquatic habitat, marshes, alvars, coastal barrier systems, sheltered embayments, nearshore bedrock mosaic, and sand dunes. New research indicates that nearshore island areas in the Ontario waters of Lake Huron account for 58% of the fish spawning and nursery habitat and thus are critically important to the Great Lakes fishery. Many of Ontario's provincially rare species and vegetation communities can be found on islands in the Great Lakes.

Pressures
By their very nature, islands are more sensitive to human influence than the mainland and need special protection to conserve their natural values. Proposals to develop islands are increasing. This is occurring before we have the scientific information about sustainable use to evaluate, prioritize, and make appropriate natural resource decisions on islands. Island stressors include development, invasive species, shoreline modification, marina and air strip development, agriculture and forestry practices, recreational use, navigation/shipping practices, wastewater discharge, mining practices, drainage or diversion systems, overpopulation of certain species such as deer, industrial discharge, development of roads or utilities, abandoned landfills, and disruption of natural disturbance regimes.

Management Implications
Based on the results of assessments of island values, biological significance, categorization, and ranking, the Binational Collaborative for the Conservation of Great Lakes Islands will soon recommend management strategies on Great Lakes islands to preserve the unique ecological features that make islands so important. In addition, based on a proposed threat assessment to be completed in 2005, the Collaborative will recommend management strategies to reduce the pressures on a set of priority island areas.

Comments from the author(s)
The Great Lakes islands provide a unique opportunity to protect a resource of global importance because many islands still remain intact. The U.S. Fish and Wildlife Service's Great Lakes Basin Ecosystem Team (GLBET) has taken on the charge of providing leadership to coordinate and improve the protection and management of the islands of the Great Lakes. The GLBET island initiative includes the coordination and compilation of island geospatial data and information, developing standardized survey/monitoring protocols, holding an island workshop in the fall of 2002 to incorporate input from partners for addressing the Great Lakes Island indicator needs, and completion of a Great Lakes Island Conservation Strategic Plan.

A subset of the GLBET formed the Binational Collaborative for the Conservation of Great Lakes Islands. Recently, the Collaborative received a habitat grant from the Environmental Protection

Agency's Great Lakes National Program Office (GLNPO) to develop a framework for the binational conservation of Great Lakes islands. With this funding, the team has developed:
1) An island biodiversity assessment and ranking system (based on a subset of biodiversity parameters) that will provide a foundation to prioritize island conservation;
2) A freshwater island classification system; and
3) A suite of indicators that can be monitored to assess change, threats, and progress towards conservation of Great Lakes islands biodiversity.

To date, the Collaborative has tentatively proposed ten state, five pressure, and two response indicators. We anticipate developing additional response indicators and may be able to incorporate existing Great Lakes response indicators. The island indicators are still being evaluated and are not final. Final selection of indicators will take place in 2005-2006, and will be based on relevance, feasibility, response variability, and interpretation and utility. The Collaborative is currently drafting the Framework for the Binational Conservation of Great Lakes Islands, which is expected to be submitted for public and peer review in the fall of 2006.

The information conveyed by a science-based suite of island indicators will help to focus attention and management efforts to best conserve these unique and globally significant Great Lakes resources.

Acknowledgments
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Last updated

SOLEC 2006

Costal Environment	No. Individual Islands	No. Islands/ Complexes	Biodiversity Score		Threat Score	
			Mean	Range	Mean	Range
Georgian Bay 1	3992	595	85.2	0-345	1.3	0-65
Georgian Bay 2	17615	848	90.2	0-290	11.8	0-52
Georgian Bay 3	38	22	93.9	57-244	8.2	1-46
Georgian Bay 4	36	18	95.8	47-195	5.7	1-33
Georgian Bay 5	290	90	103.6	39-300	4.0	1-44
Georgian Bay 6	225	119	92.8	46-401	9.7	1-581
Lake Erie 1	0	0	0	0	0	0
Lake Erie 2	15	15	151.7	87-388	11.2	1-88
Lake Erie 3	2	2	92.5	91-94	1.0	1
Lake Erie 4	66	13	198.9	154-340	4.8	1-32
Lake Erie 5	2	2	90.5	87-94	2.0	1-3
Lake Erie 6	1461	30	203.4	81-333	9.7	1-41
Lake Erie 7	21	18	88.4	57-143	7.7	1-42
Lake Erie 8	17	4	144.5	96-164	2.3	1-6
Lake Huron 1	887	173	103.4	39-490	8.2	1-179
Lake Huron 2	31	19	85.0	57-137	3.4	1-22
Lake Huron 3	8	5	127.0	114-145	2.8	1-4
Lake Ontario 1	0	0	0	0	0	0
Lake Ontario 2	9	7	108.6	90-148	2.3	1-5
Lake Ontario 3	34	13	127.0	86-190	7.0	1-27
Lake Ontario 4	74	32	131.5	83-231	3.3	1-22
Lake Ontario 5	603	171	114.1	44-302	3.7	1-143
Lake Superior 1	167	117	84.6	39-290	2.2	1-25
Lake Superior 2	1228	459	81.2	37-288	2.0	1-40
Lake Superior 3	495	160	71.7	40-195	2.4	1-28
Lake Superior 4	77	28	97.2	57-253	3.3	1-26
Lake Superior 5	246	45	93.6	49-275	8.8	1-138
St. Clair 1	21	11	119.7	84-187	22.1	1-46
St. Clair 2	234	25	162.2	92-336	9.2	1-68
St. Clair 3	53	11	160.3	102-239	6.0	1-36
St. Clair 4	1	1	116	116	2	2
St. Clair 5	41	14	162.1	79-231	11.5	1-36
St. Lawrence 1	337	111	92.4	44-211	19.5	1-81

Table 1. Biodiversity and Threats Scores for Great Lakes Islands (Canada only), by coastal environment.
Source: Framework for Binational Conservation of Great Lakes Islands

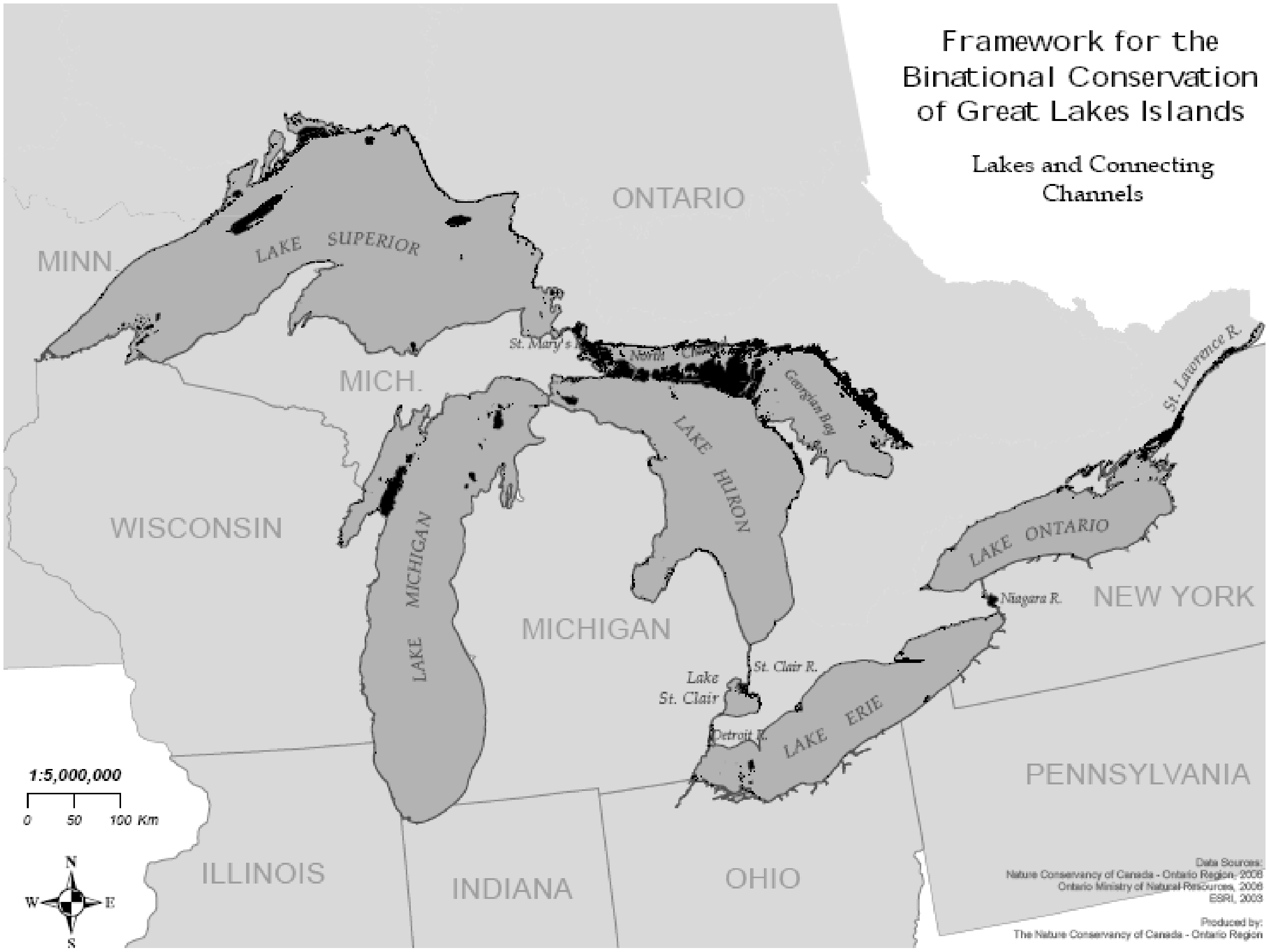

Figure 1. Islands of the Great Lakes.
Source: Framework for the Binational Conservation of Great Lakes Islands

Extent of Hardened Shoreline

Indicator #8131

Assessment: Mixed, Deteriorating

Purpose

- To assess the extent (in kilometres) of hardened shoreline along the Great Lakes through construction of sheet piling, rip rap, or other erosion control structures.

Ecosystem Objective

Shoreline conditions should be healthy enough to support aquatic and terrestrial plant and animal life, including the rarest species.

State of the Ecosystem

Background

Anthropogenic hardening of the shorelines not only directly destroys natural features and biological communities, it also has a more subtle but still devastating impact. Many of the biological communities along the Great Lakes are dependent upon the transport of shoreline sediment by lake currents. Altering the transport of sediment disrupts the balance of accretion and erosion of materials carried along the shoreline by wave action and lake currents. The resulting loss of sediment replenishment can intensify the effects of erosion, causing ecological and economic impacts. Erosion of sand spits and other barriers allows increased exposure of the shoreline and loss of coastal wetlands. Dune formations can be lost or reduced due to lack of adequate nourishment of new sand to replace sand that is carried away. Increased erosion also causes property damage to shoreline properties.

Status of Hardened Shorelines in the Great Lakes

The National Oceanic and Atmospheric Administration (NOAA) Medium Resolution Digital Shorelines dataset was compiled between 1988 and 1992. It contains data on both the Canadian and U.S. shorelines, using aerial photography from 1979 for the state of Michigan and from 1987-1989 for the rest of the basin.

From this dataset, shoreline hardening has been categorized for each Lake and connecting channel (Table 1). Figure 1 indicates the percentages of shorelines in each of these categories. The St. Clair, Detroit, and Niagara Rivers have a higher percentage of their shorelines hardened than anywhere else in the basin.

Of the Lakes themselves, Lake Erie has the highest percentage of its shoreline hardened, and Lakes Huron and Superior have the lowest (Figure 2). In 1999, Environment Canada assessed change in the extent of shoreline hardening along about 22 kilometres of the Canadian shoreline of the St. Clair River from 1991-1992 to 1999. Over the eight-year period, an additional 5.5 kilometers (32%) of the shoreline had been hardened. This is clearly not representative of the overall basin, as the St. Clair River is a narrow shipping channel with high volumes of Great Lakes traffic. This area also has experienced significant development along its shorelines, and many property owners are hardening the shoreline to reduce the impacts of erosion.

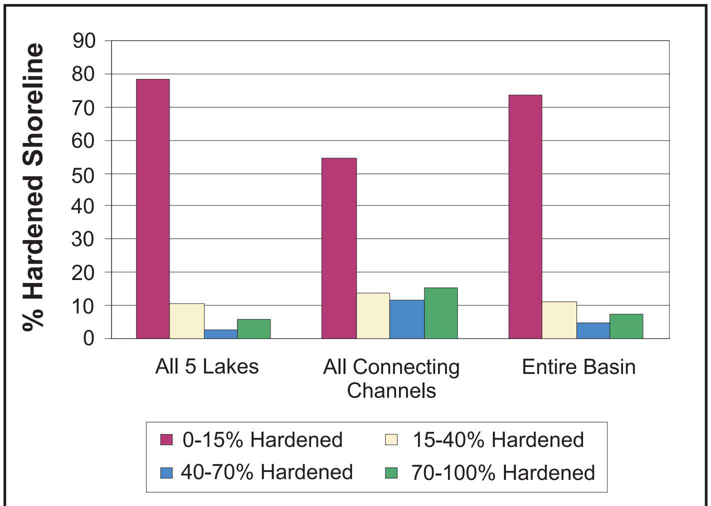

Figure 1. Shoreline hardening in the Great Lakes compiled from 1979 data for the state of Michigan and 1987-1989 data for the rest of the basin.
Source: Environment Canada and National Oceanic and Atmospheric Administration

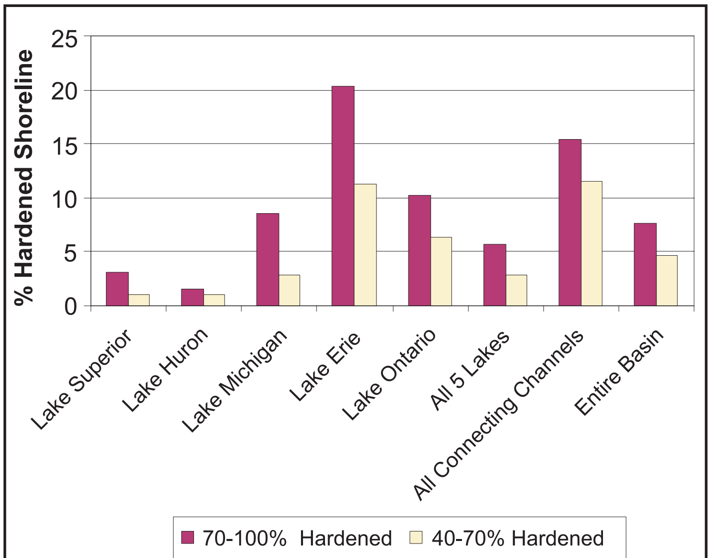

Figure 2. Shoreline hardened by lake compiled from 1979 data fro the state of Michigan and 1987-1989 for the rest of the basin.
Source: Environment Canada and National Oceanic and Atmospheric Administration

Lake / Connecting Channel	70 - 100% Hardened	40 - 70% Hardened	15 - 40% Hardened	0 - 15% Hardened	Non-structural Modifications	Unclassified	Total Shoreline (km)
Lake Superior	3.1	1.1	3.0	89.4	0.03	3.4	5,080
St. Marys River	2.9	1.6	7.5	81.3	1.6	5.1	707
Lake Huron	1.5	1.0	4.5	91.6	1.1	0.3	6,366
Lake Michigan	8.6	2.9	30.3	57.5	0.1	0.5	2,713
St. Clair River	69.3	24.9	2.1	3.6	0.0	0.0	100
Lake St. Clair	11.3	25.8	11.8	50.7	0.2	0.1	629
Detroit River	47.2	22.6	8.0	22.2	0.0	0.0	244
Lake Erie	20.4	11.3	16.9	49.1	1.9	0.4	1,608
Niagara River	44.3	8.8	16.7	29.3	0.0	0.9	184
Lake Ontario	10.2	6.3	18.6	57.2	0.0	7.7	1,772
St. Lawrence Seaway	12.6	9.3	17.2	54.7	0.0	6.2	2,571
All 5 Lakes	5.7	2.8	10.6	78.3	0.6	2.0	17,539
All Connecting Channels	15.4	11.5	14.0	54.4	0.3	4.4	4,436
Entire Basin	7.6	4.6	11.3	73.5	0.5	2.5	21,974

Table 1. Percentages of shorelines in each category of hardened shoreline. The St. Clair, Detroit and Niagara Rivers have a higher percentage of their shorelines hardened than anywhere else in the basin. Lake Erie has the highest percentage of its shoreline hardened, and Lakes Huron and Superior have the lowest.
Source: National Oceanic and Atmospheric Administration

Pressures

Shoreline hardening is generally not reversible, so once a section of shoreline has been hardened it can be considered a permanent feature. As such, the current state of shoreline hardening likely represents the best condition that can be expected in the future. Additional stretches of shoreline will continue to be hardened, especially during periods of high lake levels. This additional hardening in turn will starve the downcurrent areas of sediment to replenish that which eroded away, causing further erosion and further incentive for additional hardening. Thus, a cycle of shoreline hardening can progress along the shoreline. The future pressures on the ecosystem resulting from existing hardening will almost certainly continue, and additional hardening is likely in the future. The uncertainly is whether the rate can be reduced and ultimately halted. In addition to the economic costs, the ecological costs are of concern, particularly the percent further lost or degradation of coastal wetlands and sand dunes.

Management Implications

Shoreline hardening can be controversial, even litigious, when one property owner hardens a stretch of shoreline that may increase erosion of an adjacent property. The ecological impacts are not only difficult to quantify as a monetary equivalent, but difficult to perceive without an understanding of sediment transport along the lakeshores. The importance of the ecological process of sediment transport needs to be better understood as an incentive to reduce new shoreline hardening. An educated public is critical to ensuring wise decisions about the stewardship of the Great Lakes basin ecosystem, and better platforms for getting understandable information to the public is needed.

Acknowledgments

Authors: John Schneider, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL; Duane Heaton, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL; and Harold Leadlay, Environment Canada, Environmental Emergencies Section, Downsview, ON.

Sources

The National Geophysical Data Center, National Oceanic and Atmospheric Administration (NOAA). Medium resolution digital shoreline, 1988-1992. In *Great Lakes Electronic Environmental Sensitivity Atlas*, Environment Canada, Environmental Protection Branch, Downsview, ON.

Authors' Commentary

It is possible that current aerial photography of the shoreline will be interpreted to show more recently hardened shorelines. Once more recent data provides information on hardened areas, updates may only be necessary basin-wide every 10 years, with monitoring of high-risk areas every 5 years.

Last Updated

State of the Great Lakes 2001

Contaminants Affecting Productivity of Bald Eagles

Indicator #8135

Assessment: Mixed, Improving

Purpose

- To assess the number of territorial pairs, success rate of nesting attempts, and number of fledged young per territorial pair as well as the number of developmental deformities in young bald eagles;
- To measure concentrations of persistent organic pollutants and selected heavy metals in unhatched bald eagle eggs and in nestling blood and feathers; and
- To infer the potential for harm to other wildlife caused by eating contaminated prey items.

Ecosystem Objectives

This indicator supports annexes 2, 12, and 17 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

As the top avian predator in the nearshore and tributary areas of the Great Lakes, the bald eagle integrates contaminant stresses, food availability, and the availability of relatively undeveloped habitat areas over most portions of the Great Lakes shoreline. It serves as an indicator of both habitat quantity and quality.

Figure 1. Approximate nesting locations of bald eagles (in red) along the Great Lakes shorelines, 2000.
Source: W. Bowerman, Clemson University, Lake Superior LaMPs, and for Lake Ontario, Peter Nye, and N.Y. Department of Environmental Conservation

Concentrations of organochlorine chemicals are decreasing or stable but still above No Observable Adverse Effect Concentrations (NOAECs) for the primary organic contaminants, dichlorodiphenyl-dichloroethene (DDE) and polychlorinated biphenyls (PCBs). Bald eagles are now distributed extensively along the shoreline of the Great Lakes (Figure 1). The number of active bald eagle territories has increased markedly from the depths of the population decline caused by DDE (Figure 2). Similarly, the percentage of nests producing one or more fledglings (Figure 3) and the number of young produced per territory (Figure 4) have risen. The recovery of reproductive output at the population level has followed similar patterns in each of the lakes, but the timing has differed between the various lakes. Lake Superior recovered first, followed by Erie and Huron, and most recently, Lake Michigan. An active territory has been reported from Lake Ontario. Established territories in most areas are now producing one or more young per territory indicating that the population is healthy and capable of growing. Eleven developmental deformities have been reported in bald eagles within the Great Lakes watershed; five of these were from territories potentially influenced by the Great Lakes.

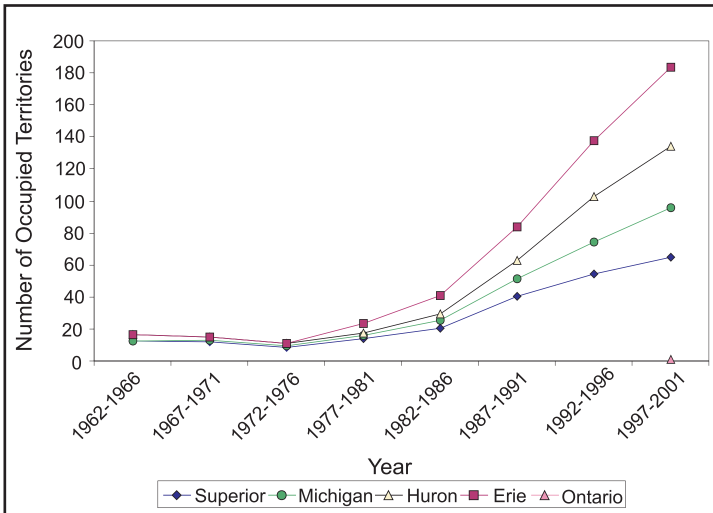

Figure 2. Average number of occupied bald eagle territories per year by lake.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources

Pressures

High levels of persistent contaminants in bald eagles continue to be a concern for two reasons. Eagles are relatively rare and contaminant effects on individuals can be important to the well-being of local populations. In addition, relatively large habitat units are necessary to support eagles and continued development pressures along the shorelines of the

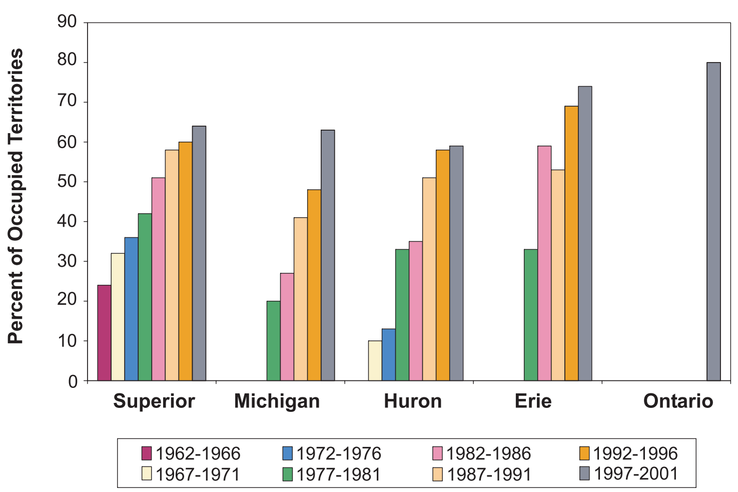

Figure 3. Average percentage of occupied territories fledging at least one young.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources

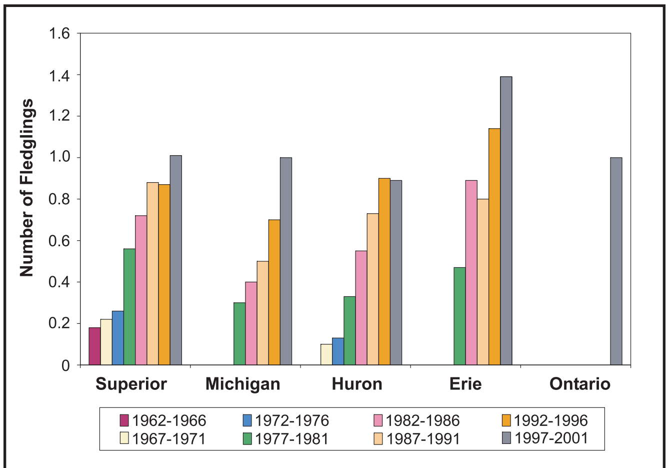

Figure 4. Average number of young fledged per occupied territory per year.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources

Great Lakes constitute a concern. The interactions of contaminant pressures and habitat limitations are unknown at present. There are still several large portions of the Great Lakes shoreline, particularly around Lake Ontario, where the bald eagle has not recovered to its pre-DDE status despite what appears to be adequate habitat in many areas.

Management Implications

The data on reproductive rates in the shoreline populations of Great Lakes bald eagles imply that widespread effects of persistent organic pollutants have decreased. However, there are still gaps in this pattern of reproductive recovery that should be explored and appropriate corrective actions taken. In addition, information on the genetic structure of these shoreline populations is still lacking. It is possible that further monitoring will reveal that these populations are being maintained from surplus production from inland sources rather than from the productivity of the shoreline birds themselves. Continued expansion of these populations into previously unoccupied areas is encouraging and might indicate several things; there is still suitably undeveloped habitat available, or bald eagles are adapting to increasing alteration of the available habitat.

Acknowledgments

Authors: Ken Stromborg, U.S. Fish & Wildlife Service;
David Best, U.S. Fish & Wildlife Service;
Pamela Martin, Canadian Wildlife Service; and
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Authors' Commentary

Monitoring the health and contaminant status of Great Lakes bald eagles should continue across the Great Lakes basin. Even though the worst effects of persistent bioaccumulative pollutants seem to have passed, the bald eagle is a prominent indicator species that integrates effects that operate at a variety of levels within the ecosystem. Symbols such as the bald eagle are valuable for communicating with the public. Many agencies continue to accomplish the work of reproductive monitoring that results in compatible data for basin-wide assessment. However, the Wisconsin Department of Natural Resources and Ohio Department of Natural Resources programs are diminished as the result of budgetary constraints, while Michigan Department of Environmental Quality, New York State Department of Environmental Conservation and Ontario Ministry of Natural Resources programs will continue for the near future. In the very near future, when the bald eagle is removed from the list of threatened species in the United States, existing monitoring efforts may be severely curtailed. Without the required field monitoring data, overall assessments of indicators like the bald eagle will be impossible. Part of the problem with a lessened emphasis on wildlife monitoring by governmental agencies is the failure of initiatives such as the State of the Lakes Ecosystem

Conference (SOLEC) process to identify and designate programs that are essential in order to ensure that data continuity is maintained. Two particular needs for additional data also exist. There is no basin-wide effort directed toward assessing habitat suitability of shoreline areas for bald eagles. Further, it is not known to what degree the shoreline populations depend on recruiting surplus young from healthy inland populations to maintain the current rate of expansion or whether shoreline populations are self-sustaining.

Last Updated
State of the Great Lakes 2005

Population Monitoring and Contaminants Affecting the American Otter

Indicator #8147

Assessment: Mixed, Trend Not Assessed

Purpose

- To directly measure the contaminant concentrations found in American otter populations within the Great Lakes basin; and
- To indirectly measure the health of Great Lakes habitat, progress in Great Lakes ecosystem management, and/or concentrations of contaminants present in the Great Lakes.

Ecosystem Objective

As a society we have a moral responsibility to sustain healthy populations of American otter in the Great Lakes/St. Lawrence basin. American otter populations in the upper Great Lakes should be maintained, and restored as sustainable populations in all Great Lakes coastal zones, lower Lake Michigan, western Lake Ontario, and Lake Erie watersheds and shorelines. Great Lakes shoreline and watershed populations of American otter should have an annual mean production of >2 young/adult female; and concentrations of heavy metal and organic contaminants in otter tissue samples should be less than the No Observable Adverse Effect Level found in tissue sample from mink. The importance of the American otter as a biosentinel is related to International Joint Commission Desired Outcomes 6: Biological Community Integrity and Diversity, and 7: Virtual Elimination of Inputs of Persistent Toxic Chemicals.

State of the Ecosystem

A review of State and Provincial otter population data indicates that primary areas of population suppression still exist in southern Lake Huron watersheds, lower Lake Michigan and most Lake Erie watersheds. Data provided from New York Department of Environmental Conservation (NYDEC) and Ontario Ministry of Natural Resources (OMNR) suggest that otter are almost absent in western Lake Ontario (Figure 1). Most coastal shoreline areas have more suppressed populations than interior zones.

Areas of otter population suppression are directly related to human population centers and subsequent habitat loss, and also to elevated contaminant concentrations associated with human activity. Little statistically-viable population data exist for the Great Lakes populations, and all suggested population levels illustrated were determined from coarse population assessment methods.

Pressures

American otters are a direct link to organic and heavy metal concentrations in the food chain. It is a relatively sedentary species and subsequently synthesizes contaminants from smaller areas than wider-ranging organisms, e.g. bald eagle. Contaminants are a potential and existing problem for many otter populations throughout the Great Lakes. Globally, indications of contaminant problems in otter have been noted by decreased population levels, morphological abnormalities (i.e. decreased baculum length) and decline in fecundity. Changes in the species population and range are also representative of anthropogenic riverine and lacustrine habitat alterations.

Management Implications

Michigan and Wisconsin have indicated a need for an independent survey using aerial survey methods to index otter populations in their respective jurisdictions. Minnesota has already started aerial population surveys for otter. Subsequently, some presence-absence data may be available for Great Lakes watersheds and coastal populations in the near future. In addition, if the surveys are conducted frequently, the trend data may become useful. There was agreement among resource managers on the merits of aerial survey methods to index otter populations, although these methods are only appropriate in areas with adequate snow cover. NYDEC, OMNR, Federal jurisdictions and

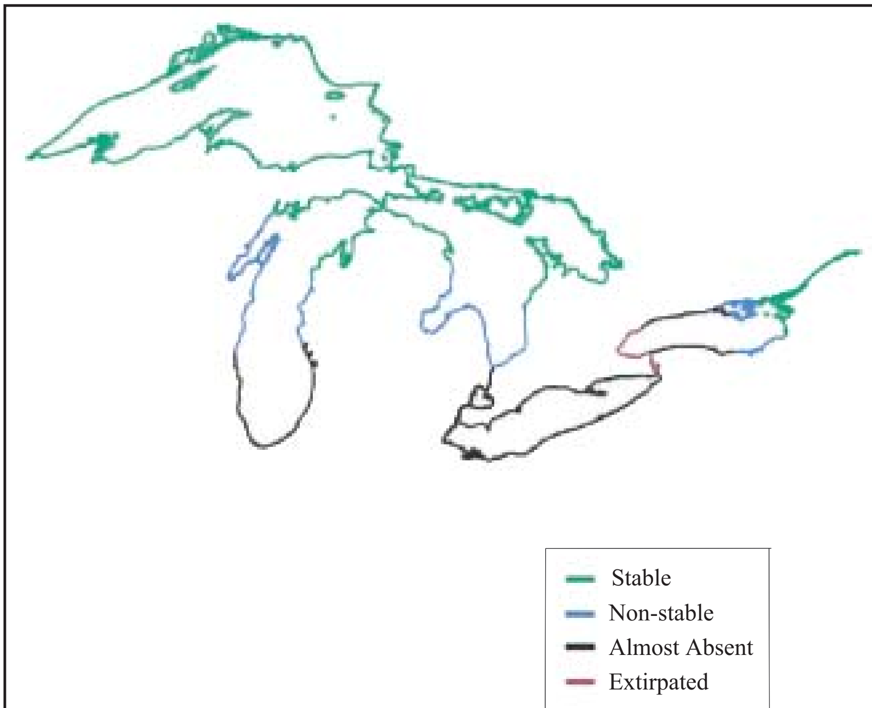

Figure 1. Great Lakes shoreline population stability estimates for the American otter.
Source: Thomas C.J. Doolittle, Bad River Band of Lake Superior Tribe of Chippewa Indians

Tribes on Great Lakes coasts indicated strong needs for future assessments of contaminants in American otter. Funding, other than from sportsmen, is needed by all jurisdictions to assess habitats and contaminant levels, and to conduct aerial surveys.

Acknowledgments
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Authors' Commentary

All State and Provincial jurisdictions use different population assessment methods, making comparisons difficult. Most jurisdictions use survey methods to determine populations on state- or provincial-wide scales. Most coarse population assessment methods were developed to assure that trapping was not limiting populations and that otter were simply surviving and reproducing in their jurisdiction. There was little work done on finer spatial scales using otter as an indicator of ecosystem heath.

In summary, all state and provincial jurisdictions only marginally index Great Lakes watershed populations by presence-absence surveys, track surveys, observations, trapper surveys, population models, aerial surveys, and trapper registration data.

Michigan has the most useful spatial data that could index the largest extent of Great Lakes coastal populations due to their registration requirements. Michigan registers trapped otter to an accuracy of 1 square mile. However, other population measures of otter health, such as reproductive rates, age and morphological measures, are not tied to spatial data in any jurisdiction, but are pooled together for entire jurisdictions. If carcasses are collected for necropsy, the samples are usually too small to accurately define health of Great Lakes coastal otter verses interior populations. Subsequently, there is a large need to encourage and fund resource management agencies to streamline data for targeted population and contaminant research on Great Lakes otter populations, especially in coastal zones.

Last Updated

State of the Great Lakes 2003

Biodiversity Conservation Sites
Indicator #8164

Overall Assessment

Status:	**Not Assessed**
Trend:	**Undetermined**
Primary Factors Determining Status and Trend	Information on Biodiversity Conservation sites is limited at this time making it difficult to assess the status and trend of this indicator.

Lake-by-Lake Assessment

Lake Superior

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Michigan

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Huron

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Erie

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Ontario

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Purpose
- To assess and monitor the biodiversity of the Great Lakes watershed.

Ecosystem Objective
The ultimate goal of this indicator is to generate and implement a distinct conservation goal for each target species, natural community type and aquatic system type within the Great Lakes basin. Through establishing the long-term survival of viable populations, the current level of biodiversity within the region can be maintained, or even increased. This indicator supports Great Lakes Quality Agreement Annexes 1, 2 and 11.

State of the Ecosystem
Background
In 1997, the Great Lakes Program of The Nature Conservancy (TNC) launched an initiative to identify high priority biodiversity conservation sites in the Great Lakes region. Working with experts from a variety of agencies, organizations, and other public and private entities throughout the region, a collection of conservation targets was identified. These targets, which represented the full range of biological diversity within the region, consisted of globally rare plant and animal species, naturally occurring community types within the ecoregion, and all aquatic system types found in the Great Lakes watershed.

In order to ensure the long-term survival of these conservation targets, two specific questions were asked: how many populations or examples of each target are necessary to ensure its long-term survival in the Great Lakes ecoregion, and how should these populations or examples be distributed in order to capture the target's genetic and ecological variability across the Great Lakes ecoregion? Using this information, which is still limited as these questions have not been satisfactorily answered in the field of conservation biology, a customized working hypothesis, i.e. conservation goal, was generated for each individual conservation target. Additionally, to effectively and efficiently achieve these conservation goals, specific portfolio sites were identified. These sites, many of which contain more than one individual target, support the most viable examples of each target, thus aiding in the preservation of the overall biodiversity within the Great Lakes region.

With support from TNC, the Nature Conservancy of Canada has undertaken a similar initiative, identifying additional targets, goals, and conservation sites within Ontario, Canada. However, as the commencement of this project occurred some time after the U.S. counterpart, there is a wide discrepancy in the information that is currently available.

Status of Biodiversity Conservation Sites in the Great Lakes Basin
Within the U.S. portion of the Great Lakes region, 208 species (51 plant species, 77 animal species and 80 bird species) were identified. Of these, 18 plant species and 28 animal species can be considered endemic (found only in the Great Lakes region) or limited (range is primarily in the Great Lakes ecoregion, but also extends into one or two other ecoregions). Furthermore, 24 animals and 14 plants found within the basin are recognized as globally imperiled. Additionally, 274 distinct natural community types are located throughout the ecoregion: 71 of which are endemic or largely limited to the Great Lakes, while 45 are globally imperiled. The Great Lakes

watershed also contains 231 aquatic system types, all of which are inextricably connected to the region, and thus do not occur outside this geographical area.

A total of 501 individual portfolio sites have been designated throughout the Great Lakes region: 280 of which reside fully within the U.S., 213 are located entirely in Canada, while the remaining 8 sites cross international borders. However, there is an uneven distribution among the conservation priority sites found in the U.S., as over half are completely or partially located within the state of Michigan. New York State contains the second greatest number of sites with 56; Wisconsin, 29; Ohio, 25; and Minnesota, 20. Furthermore, 9 sites are located within the state of Illinois, 7 sites in Indiana, while only 2 sites are found in the state of Pennsylvania (11 sites cross state borders, while one international and one U.S. site cross more than one border). The sizes of the selected portfolio sites have a wide distribution, ranging from approximately 60 to 1,500,000 acres; with three-fourths of the sites having areas which are less than 20,000 acres.

The currently established conservation sites provide enough viable examples to fully meet the conservation goals for 20% of the 128 species and 274 community types described within the Great Lakes conservation vision. Additionally, under the existing Conservation Blueprint, 80% of the aquatic systems are sufficiently represented in order to meet their conservation goals. However, these figures might not present an accurate depiction of the current state of the biodiversity within the region. Due to a lack of available data for several species, communities, and aquatic systems, a generalized conservation goal, e.g. “all viable examples” was established for these targets. As such, even though the conservation goals may have been met, there might not be an adequate number of examples to ensure the long-term survival of these targets.

In order to sustain the current level of biodiversity, i.e. number of targets that have met their conservation goals, attention to the health and overall integrity of the conservation sites must be maintained. While approximately 60% of these sites are irreplaceable, these places represent the only opportunity to protect certain species, natural communities, aquatic systems, or assemblages of these targets within the Great Lakes region. Only 5% of all U.S. sites are actually fully protected. Furthermore, 79% of the Great Lakes sites require conservation attention within the next ten years, while more than one-third of the sites need immediate attention in order to protect conservation targets. These conservation actions range from changes in policies affecting land use, i.e. specific land protection measures (conservation easements or changes in ownership), to the modification of the management practices currently used.

Pressures

In the U.S., information was obtained from 224 sites regarding pressures associated with the plants, animals, and community targets within the Great Lakes basin: from this data four main threats emerged. The top threat to biodiversity sites throughout the region is currently development, i.e. urban, residential, second home, and road, as it is affecting approximately two-thirds of the sites in the form of degradation, fragmentation, or even the complete loss of these critical habitats. The second significant threat, affecting the integrity of more than half the sites, is the impact exerted by invasive species, which includes non-indigenous species such as purple loosestrife, reed canary grass, garlic mustard, buckthorn, zebra mussels, and exotic fishes, as well as high-impact, invasive, native species such as deer. Affecting almost half of the U.S. sites, hydrology alteration, the third most common threat to native biodiversity, includes threats due to dams, diversions, dikes, groundwater withdrawals, and other changes to the natural flow regime.

Finally, recreation (boating, camping, biking, hiking, etc.) is a major threat that affects over 40% of the sites.

Management Implications

A continuous effort to obtain pertinent information is essential in order to maintain the most scientifically-based conservation goals and strategies for each target species, community and aquatic system type within the Great Lakes basin. Additional inventories are also needed in many areas to further assess the location, distribution and viability of individual targets, especially those that are more common throughout the region. Furthermore, even though current monitoring efforts and conservation actions are being implemented throughout the watershed, they are generally site-specific or locally concentrated. A greater emphasis on a regional-wide approach must be undertaken if the long-term survival of these metapopulations is to be ensured. This expanded perspective would also assist in establishing region-wide communications, thus enabling a more rapid and greater distribution of information. However, the establishment of basin-wide management practices is greatly hindered by the numerous governments represented throughout this region, (two federal governments, 100 tribal authorities, one province, and eight states (each with multiply agencies), 13 regional and 18 county municipalities in Ontario, 192 counties in the US and thousands of local governments) and the array of land-use policies developed by each administrations. Without additional land protection measures, it will be difficult to preserve the current sites and implement restoration efforts in order to meet the conservation goals for the individual conservation targets.

Acknowledgments

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Contributors: Mary Harkness, The Nature Conservancy.

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List of Figures

Last updated

SOLEC 2006

Figure 1. Map of Biodiversity Conservation Sites within the Great Lakes Region.
http://www.nature.org/wherewework/northamerica/greatlakes/files/tnc_great_lakes_web.pdf

Forest Lands - Conservation of Biological Diversity
Indicator #8500

Note: This indicator includes four components that correspond to Montreal Process Criterion #1, Indicators 1, 2, 3, and 5.

Indicator #8500 Components:
- Component (1) – Extent of area by forest type relative to total forest area
- Component (2) – Extent of area by forest type and by age-class or successional stage
- Component (3) – Extent of area by forest type in protected area categories
- *Component (4) – Extent of forest land conversion, parcelization, and fragmentation (Still under development for future analysis; data not presented in this report)*

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Primary Factors Determining Status and Trend: **There is a moderate distribution of forest types in the Great Lakes basin by age-class and seral stage. Additional analysis is required by forestry professionals.**

Lake-by-Lake Assessment

Lake Superior

Status: Not Assessed
Trend: Undetermined
Primary Factors Determining Status and Trend: Data by individual lake basin was not available for the U.S. at this time.

Lake Michigan

Status: Not Assessed
Trend: Undetermined
Primary Factors Determining Status and Trend: Data by individual lake basin was not available for the U.S. at this time.

Lake Huron

Status: Not Assessed
Trend: Undetermined
Primary Factors Determining Status and Trend: Data by individual lake basin was not available for the U.S. at this time.

Lake Erie

Status: Not Assessed
Trend: Undetermined
Primary Factors Determining: Data by individual lake basin was not available for the U.S. at this time.

Status and Trend

Lake Ontario

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Data by individual lake basin was not available for the U.S. at this time.

Purpose

•To describe the extent, composition and structure of Great Lakes basin forests; and
•To address the capacity of forests to perform the hydrologic functions and host the organisms and essential processes that are essential to protecting the biological diversity, physical integrity and water quality of the watershed.

Ecosystem Objective

To have a forest composition and structure that most efficiently conserves the natural biological diversity of the region

State of the Ecosystem

Component (1):
Forests cover over half (61%), of the land in the Great Lakes basin. The U.S. portion of the basin has forest coverage on 54% of its land, while the Canadian portion has coverage on 73% of its land.

In the U.S. portion of the basin, maple-beech-birch is the most extensive forest type, representing 7.8 million hectares, or 39% of total forest area in the basin. Aspen-birch forests constitute the second-largest forest type, covering 19% of the total. Complete data are available in Table 1 and are visually represented in Figure 1.

The entire Canadian portion of the basin is dominated by mixed forest, representing 39% of the total forest area, followed by hardwoods, covering 23% of the total forest area analyzed from satellite data, (see Table 2A). The most extensive provincial forest type is the upland mixed conifer, representing 23% of the forested area available for analysis, followed by the mixedwoods, tolerant hardwoods, white birch, and poplars, (see Figure 2 and Table 2B).

Implications for the health of Great Lakes forests and the basin ecosystem are difficult to establish. There is no consensus on how much land in the basin should be forested; much less on how much land should be covered by each forest type. Generally speaking, maintenance of the variety of forest types is important in species preservation, and long-term changes in forest type proportions are indicative of changes in forest biodiversity patterns, (OMNR 2002).

Comparisons to historical forest cover, although of limited utility in developing landscape goals, can illustrate the range of variation experienced within the basin since the time of European settlement. (See supplemental section entitled "Historical Range of Variation in the Great Lakes Forests of Minnesota, Wisconsin and Michigan" in the State of the Great Lakes 2005 version of this indicator report, #8500, for more information). Analysis of similar historical forest cover data for the entire Great Lakes Basin over the past several years would be useful in establishing current trends to help assess potential changes to ecosystem function and community diversity.

Component (2):
In the U.S. portion of the basin, the 41-60 and 61-80 year age-classes are dominant and together represent about 41% of total forest area. Forests 40 years of age and under make up a further 30%, while those in the 100+ year age-classes constitute 7% of total forest area. Table 3 contains complete U.S. data for age-class distribution as a percentage of forested area within each forest type.

Because forests are dynamic and different tree species have different growth patterns, age distribution varies by forest type. In the U.S. portion of the basin, aspen-birch forests tend to be younger, being more concentrated than other forest types in age classes under 40 years, while the Oak-Pine forests are more concentrated in the 41-60 and 61-80 year age classes, comparatively. Spruce-fir and Oak-Hickory forests have a general distribution centered around 41-80 years, but also have the highest amount of oldest trees, representing about 10% each of total forest area in the 100+ year age class, (see Figure 3).

This age-class data can serve as a coarse surrogate for the vegetative structure (height and diameter) of a forest, and can be combined with data from other indicators to provide insight on forest sustainability.

U.S data on the extent of forest area by successional or seral stage is not available. Although certain tree species can be associated with the various successional stages, a standard and quantifiable protocol for identifying successional stage has not yet been developed. It is expected, however, that in the absence of disturbance, the area covered by early-successional forest types, such as aspen-birch, is likely to decline as forests convert to late-successional types, such as maple-beech-birch.

Canadian forest data for this component is available by seral stage. Ontario's forests have a distribution leaning towards mature stages, representing about 50% of the total forest area analyzed. Forests in the immature stage make up the next largest group with 20% of the total, followed by those in late successional with 14%. Every Canadian forest type distribution follows this general trend except for jack pine. Complete available data for Ontario can be viewed in Table 4 and is visually represented in Figure 4.

Although the implications of this age-class and seral stage data for forest and basin health overall are unclear, some conclusions can be made. In general, water quality is most affected during the early successional stages after a disturbance to forest habitats. Nutrient levels in streams can increase during these times until the surrounding forest is able to mature, (Swank *et. al* 2000). The trend towards mature forests in Canada would therefore mean that area of the Great Lakes basin has improved water quality. Alternately, forests with balanced forest type distributions and diverse successional stages are generally considered more sustainable, (USDA Forest Service *et. al* 2003). The combined effect on ecosystem health resulting from the balance of these opposing forces would need to be determined.

Component (3):
In the U.S. basin, 7.8% of forested land is in a protected area category. Among major forest types, 8.9% of maple-beech-birch, 6.6% of aspen-birch and 9.2% of spruce-fir forests are considered to have protected status. The oak-gum-cypress category has the highest protection rate, with 19.2% of its forest area protected from harvest. Please refer to Table 1 for complete U.S. data.

In the entire Canadian portion of the basin, 10.6% of forest area, or 1.6 million hectares, are protected, (see Table 2A). For the region of Ontario that has available forest type data, protection rates range from 15.4% for red and white pine and 11% for white birch, to 6.4% for poplar and 5.7% for mixed conifer lowland forests, (see Table 2B).

It is difficult to assess the implications of the extent of protected forest area, since there is no consensus on what the actual proportion should be. National forest protection rates are estimated to be 8.4% in Canada (WWF 1999) and 14% in the U.S. (USDA Forest Service 2004). Despite the fact that updated trend data for protected status is not available at this time for the Great Lakes basin, earlier analyses have shown a recent general increase in protected areas, (see 2005 version of this report).

As for the range of variation in protection rates by forest types, protected areas should be representative of the diversity in forest composition within a larger area. However, defining what constitutes this "larger area" is problematic. Policymakers often have a different jurisdiction than the Great Lakes basin in mind when deciding where to locate protected areas. Also, the tree species and forest types found on an individual plot of protected land can change over time due to successional processes.

Differences among the U.S., Canadian and International Union for the Conservation of Nature (IUCN) definitions of protected areas should also be noted. The IUCN standard contains six categories of protected areas – strict nature reserves/wilderness areas, national parks, natural monuments, habitat/species management areas, protected landscapes/seascapes, and managed resource protection areas. The U.S. defines protected areas as forests "reserved from harvest by law or administrative regulation," including designated Federal Wilderness areas, National Parks and Lakeshores, and state designated areas (Smith 2004). Ontario defines protected areas as national parks, conservation reserves, and its six classes of provincial parks – wilderness, natural environment, waterway, nature reserve, historical and recreational (OMNR 2002). There is substantial overlap among the specific U.S., Ontario and IUCN definitions, and a more consistent classification system would ensure proper accounting of protected areas.

Common to the U.S., Ontario and IUCN definitions is that they only include forests in the public domain. However, there are privately-owned forests similarly reserved from harvest by land trusts, conservation easements and other initiatives. Inclusion of these forests under this indicator would provide a more complete definition of protected forest areas.

Moreover, there is debate on how protected status relates to forest sustainability, water quality, and ecosystem health. In many cases, protected status was conferred onto forests for their scenic or recreational value, which may not contribute significantly to conservation or watershed management goals. On the other hand, forests available for harvest, whether controlled by the national forest system, state or local governments, tribal governments, industry or private landowners, can be managed with the stated purpose of conserving forest and basin health through the implementation of Best Management Practices and certification under sustainable forestry programs. (For more information, refer to Indicator #8503, Forest Lands – Conservation and Maintenance of Soil and Water Resources).

Component (4):
This component is still under development, as consensus still has not been reached on definitions of forest fragmentation metrics and which ones are therefore suitable for SOLEC reporting. The proposed structure is split into the forces that drive fragmentation, (land conversion and parcelization,) and a series of forest spatial pattern descriptions based off of (as yet to be agreed upon) fragmentation metrics.

Conversion of forest land to other land-use classes is considered to be a major cause of fragmentation. Proposed metrics to describe this include the percent of forest lands converted to and from developed, agricultural, and pasture land uses. Both Canadian and U.S. data are available and can be obtained from the Ontario Ministry of Natural Resources and the USDA Natural Resources Conservation Service, Natural Resources Inventory, respectively.

Parcelization of forest lands into smaller privately owned tracks of land can lead to a disruption of continuous ecosystems and habitats and therefore increased fragmentation. A proposed metric is the average size of land holdings. Canada does not have available data for this metric, while the U.S. data should be available through the USDA Forest Service, Forest Inventory and Analysis Program and the National Woodland Owner Survey.

Data for various fragmentation metrics exists for both Canada and the U.S, but the way these metrics are viewed is drastically different. According to sources that have compiled U.S. data, fragmentation, "is viewed as a property of the landscape that contains forest… [as opposed to] a property of the forest itself," (Riitters *et. al* 2002). That inconsistency aside, data exists for Ontario for the following metrics: area, patch density and size, edge, shape, diversity and interspersion, and core area. U.S. data exists for patchiness, perforation, connectivity, edge, and interior or core forest, and is available from the USDA Forest Service and is also being compiled by the U.S. EPA. Substantial discussion is still required to refine these metrics before reporting and analysis of this component can continue.

Pressures
Urbanization, seasonal home construction and increased recreational use, (driven in part by the desire of an aging and more affluent population to spend time near natural settings,) are among the general demands being placed on forest resources nationwide.

Additional disturbances caused by lumber removal and forest fires can also alter the structure of Great Lakes basin forests.

Management Implications
Increased communication and agreement regarding the definitions and reporting methods for forest type, successional stage, protected area category and fragmentation metrics between the United States and Canada would facilitate more effective basin-wide analyses.

Reporting of U.S. forest data according to watershed as opposed to county would enable analysis by individual lake basin, therefore increasing the data's value in relation to specific water quality and biodiversity objectives.

Canadian data by forest type and seral stage for the entire Great Lakes basin in Ontario as opposed to just the Area of the Undertaking (AOU), (see definition below in *Comments* section,) would allow for a more complete analysis. This can only be accomplished if managers decide to extent forest planning inventories into the private lands in the southern regions of the province.

Managing forest lands in ways that protect the continuity of forest cover can allow for habitat protection and wildlife species mobility, therefore maintaining natural biodiversity.

Comments from the author(s)
Stakeholder discussion will be critical in identifying pressures and management implications, particularly those on a localized basis, that are specific to Great Lakes basin forests. These discussions will add to longstanding debates on strategies for sustainable forest management.

There are significant discrepancies within and between Canadian and U.S. data that made it difficult to analyze the data across the Great Lakes basin as a whole. The most pervasive problems are related to the time frame, frequency and location of forest inventories and differences in metric definitions.

Canadian Great Lakes data for provincial forest type and seral stage is only available in areas of Ontario where Forest Resources Planning Inventories occur. This region is commonly referred to as the Area of the Undertaking (AOU) and only represents about 72% of Ontario's total Great Lakes basin land area. The remainder of Ontario's forests (and therefore Ontario as a whole) can only be analyzed using satellite data, which is meant for general land use/land cover analysis and does not have a fine enough resolution to allow for more detailed investigation.

Forest inventory time frames for the U.S. also have an effect on data consistency. Although the 2002 RPA assessment was used as the data source for the U.S. portion of this report, it actually draws data from a compilation of numerous state inventory years as follows: Illinois (1998), Indiana (1998), Michigan (1993), Minnesota (1990), New York (1993), Ohio (1993), Pennsylvania (1989), and Wisconsin (1996). A re-analysis of U.S. Great Lakes basin forests with data from the same time frame would be useful.

Also, the U.S. data provided for this report was compiled by county and not by watershed, so the area of land analyzed is not necessarily completely within the Great Lakes basin and all related values are therefore skewed. This factor also made it impossible to represent the data by individual lake basin. Additional GIS analysis of the raw inventory data would be required to provide forest data by watershed.

Definition of forest type differs between the U.S. and Canada as well. In the U.S., forest cover type is done according to the predominant tree species and is divided into the nine major groups represented in this report. The Canadian provincial forest type classifications, (for which data was available for this report,) however, are based on a combination of ecological factors including dominant tree species, understory vegetation, soil, and associated tree species, (OMNR 2002). The definitions of each provincial forest type are available in Table 5. Standardization of forest type definitions between the U.S. and Ontario would be necessary for analysis across the entire Great Lakes basin.

As previously mentioned earlier in this report, the forest fragmentation component of this indicator needs additional refining before it can be included for analysis.

Acknowledgments
Authors: This report was updated by Chiara Zuccarino-Crowe, Environmental Careers Organization, on appointment to U.S. Environmental Protection Agency (US EPA), Great Lakes National Program Office (GLNPO), zuccarino-crowe.chiara@epa.gov from the State of the Great Lakes 2005 Indicator report #8500 written and prepared by associate Mervyn Han, Environmental Careers Organization, on appointment to US EPA, GLNPO. (Available online at, http://binational.net/solec/sogl2005_e.html)

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Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

Figure 3. Age-class distribution as a percentage of forested area within forest type for U.S. Great Lakes basin counties
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

Figure 4. Seral stage distribution as a percentage of forested area within provincial forest type in AOU* portion of Canadian Great Lakes Basin
Caption: * The Area of the Undertaking (AOU) land area represents 72% of total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

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Forest Type	Area (ha)	% of Total Forest Area	Protected Area (ha)	% Protected
White-Red-Jack Pine	1,791,671	8.87%	168,737	9.42%
Spruce-Fir	2,866,777	14.19%	263,216	9.18%
Loblolly-Shortleaf Pine	4,305	0.02%	0	0.00%
Oak-Pine	72,675	0.36%	4,178	5.75%
Oak-Hickory	1,988,126	9.84%	129,431	6.51%
Oak-Gum-Cypress	50,589	0.25%	9,730	19.23%
Elm-Ash-Cottonwood	1,692,069	8.37%	45,564	2.69%
Maple-Beech-Birch	7,828,700	38.75%	692,600	8.85%
Aspen-Birch	3,821,272	18.91%	252,443	6.61%
Nonstocked	88,443	0.44%	4,677	5.29%
Totals	**20,204,626**		**1,570,576**	**7.77%**

Table 1. Total forest area and protected area by forest type in U.S. Great Lakes basin counties
Caption: Non-stocked =
timberland less than 10% stocked with live trees
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

A) Canadian Great Lakes Basin				
Satellite Classes	**Area (ha)**	**% of Total Forest Area**	**Protected Area (ha)**	**% Protected**
Forest - Sparse	2,053,869	13.78%	245,118	11.93%
Forest - Hardwood	3,468,513	23.27%	361,147	10.41%
Forest - Mixed	5,750,313	38.57%	649,342	11.29%
Forest - Softwood	2,407,729	16.15%	268,753	11.16%
Swamp - Treed	49,933	0.33%	1,413	2.83%
Fen - Treed	30,197	0.20%	3,726	12.34%
Bog - Treed	436,083	2.93%	28,128	6.45%
Disturbed Forest - cuts	578,450	3.88%	8,973	1.55%
Disturbed Forest - burns	97,545	0.65%	18,628	19.10%
Disturbed Forest - regenerating	35,987	0.24%	381	1.06%
Totals	**14,908,617**		**1,585,608**	**10.64%**
B) AOU* Portion of Ontario				
Provincial Forest Type	**Area (ha)**	**% of Total Forest Area**	**Protected Area (ha)**	**% Protected**
White Birch	1,593,114	13.73%	175,261	11.00%
Mixed Conifer Lowland	1,048,126	9.03%	60,192	5.74%
Mixed Conifer Upland	2,657,086	22.90%	239,194	9.00%
Mixedwood	2,099,760	18.10%	194,682	9.27%
Jack Pine	714,165	6.15%	54,991	7.70%
Poplar	1,189,573	10.25%	75,538	6.35%
Red & White Pine	685,124	5.90%	105,682	15.43%
Tolerant Hardwoods	1,616,502	13.93%	108,993	6.74%
Totals	**11,603,450**		**1,014,533**	**8.74%**

Table 2. Total forest area and protected area by forest type in, A) Canadian Great Lakes basin, B) AOU* portion of Ontario
Caption: * The Area of the Undertaking (AOU) land area represents 72% of the total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

Forest Type	Age Class (in years)							
	0-20	21-40	41-60	61-80	81-100	100+	Mixed	not measured
White-Red-Jack Pine	13.86%	27.04%	25.41%	11.63%	7.47%	4.32%	2.40%	7.87%
Spruce-Fir	8.84%	18.55%	21.84%	17.96%	9.57%	10.23%	0.33%	12.69%
Loblolly-Shortleaf Pine	0.00%	47.96%	0.00%	52.04%	0.00%	0.00%	0.00%	0.00%
Oak-Pine	7.08%	14.58%	47.30%	18.29%	3.02%	6.49%	3.18%	0.07%
Oak-Hickory	9.43%	10.13%	18.14%	21.49%	14.14%	10.06%	11.38%	5.22%
Oak-Gum-Cypress	4.47%	36.37%	19.84%	8.75%	4.08%	0.00%	5.73%	20.76%
Elm-Ash-Cottonwood	14.03%	24.29%	23.21%	15.95%	8.58%	6.17%	5.21%	2.56%
Maple-Beech-Birch	9.25%	12.38%	21.96%	20.87%	12.31%	8.75%	6.21%	8.27%
Aspen-Birch	25.40%	19.91%	26.15%	16.64%	3.85%	1.36%	0.45%	6.25%
Nonstocked	63.98%	16.73%	2.97%	1.71%	0.00%	1.14%	0.00%	13.47%
Total	**13.29%**	**16.85%**	**22.77%**	**18.37%**	**9.65%**	**7.02%**	**4.33%**	**7.72%**

Table 3. Age-class distribution as a percentage of area within forest type for U.S. Great Lakes basin counties
Caption: Non-stocked = timberland less than 10% stocked with live trees
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

Provincial Forest Type	Seral Stage				
	Presapling	Sapling	Immature	Mature	Late Successional
White Birch	3.49%	4.52%	15.55%	63.58%	12.87%
Mixed Conifer Lowland	13.81%	9.31%	13.38%	47.00%	16.50%
Mixed Conifer Upland	5.91%	13.12%	22.51%	42.11%	16.36%
Mixedwood	4.60%	7.92%	26.06%	51.03%	10.39%
Jack Pine	8.60%	31.96%	29.24%	27.51%	2.69%
Poplar	6.60%	10.45%	18.97%	52.55%	11.43%
Red & White Pine	4.94%	3.77%	23.28%	62.95%	5.06%
Tolerant Hardwoods	1.23%	0.87%	6.40%	60.13%	31.37%
Totals	**6.00%**	**10.14%**	**20.12%**	**49.84%**	**13.91%**

Table 4. Seral stage distribution as a percentage of area within provincial forest type in AOU* portion of Canadian Great Lakes Basin
Caption: * The Area of the Undertaking (AOU) land area represents 72% of the total land area analyzed in Ontario's portion of the Great Lakes basin.

Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

Provicial Forest Type	Description
White Birch	predominantly white birch stands
Upland Conifers	predominantly spruce and mixed jack pine/spruce stands on upland sites
Lowland Conifers	predominantly black spruce stands on low, poorly drained sites
Mixedwood	mixed stands made up mostly of spruce, jack pine, fir, poplar and white birch
Jack Pine	predominantly jack pine stands
Poplar	predominantly poplar stands
White and Red Pine	all red and white pine mixedwood stands
Tolerant Hardwoods	predominantly hardwoods such as maple and oak, found mostly in the Great Lakes forest region

Table 5. Description of Canadian provincial forest types
Source: Descriptions taken from, *Forest Resources of Ontario 2001: State of the Forest Report, Appendix 1*, p. 41, (OMNR 2002).

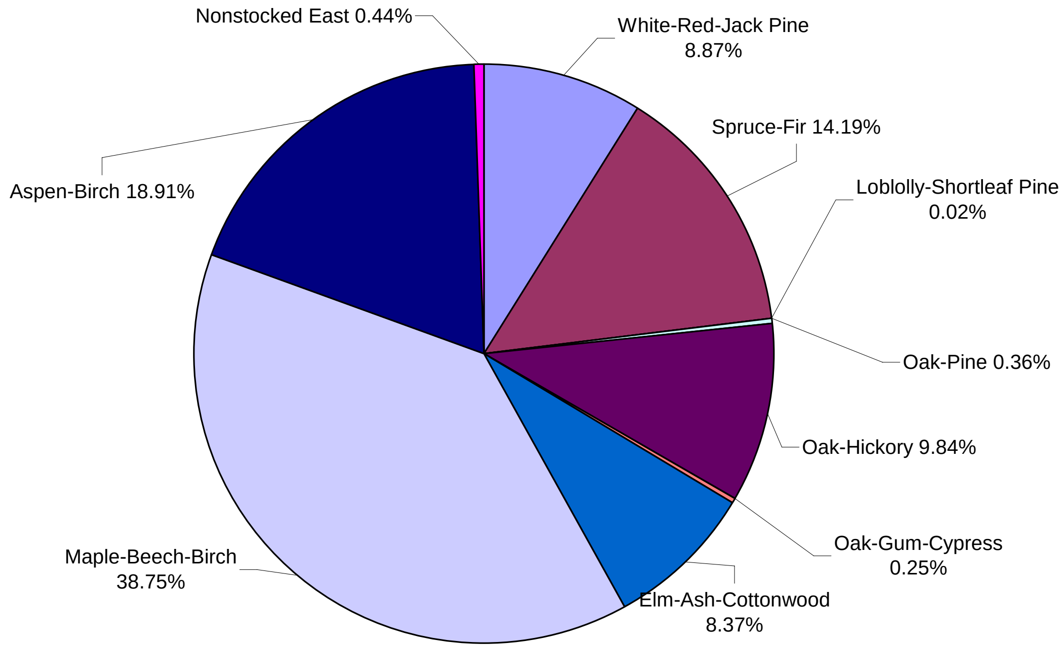

Figure 1. Proportion of forested area by forest type in U.S. Great Lakes basin
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

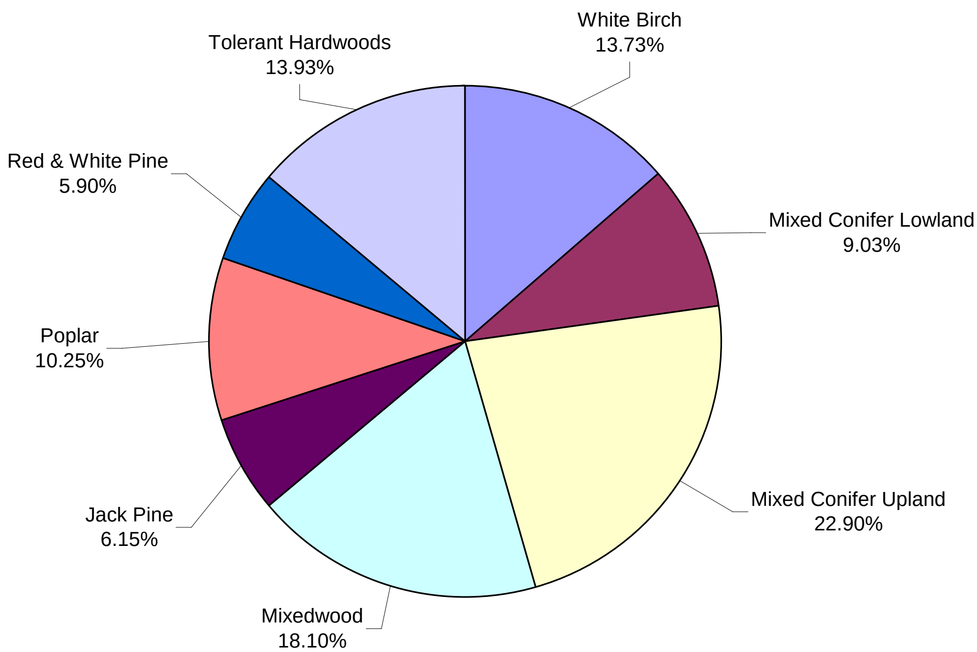

Figure 2. Proportion of forested area by provincial forest type in AOU* portion of Canadian Great Lakes basin
Caption: * The Area of the Undertaking (AOU) land area represents 72% of the total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

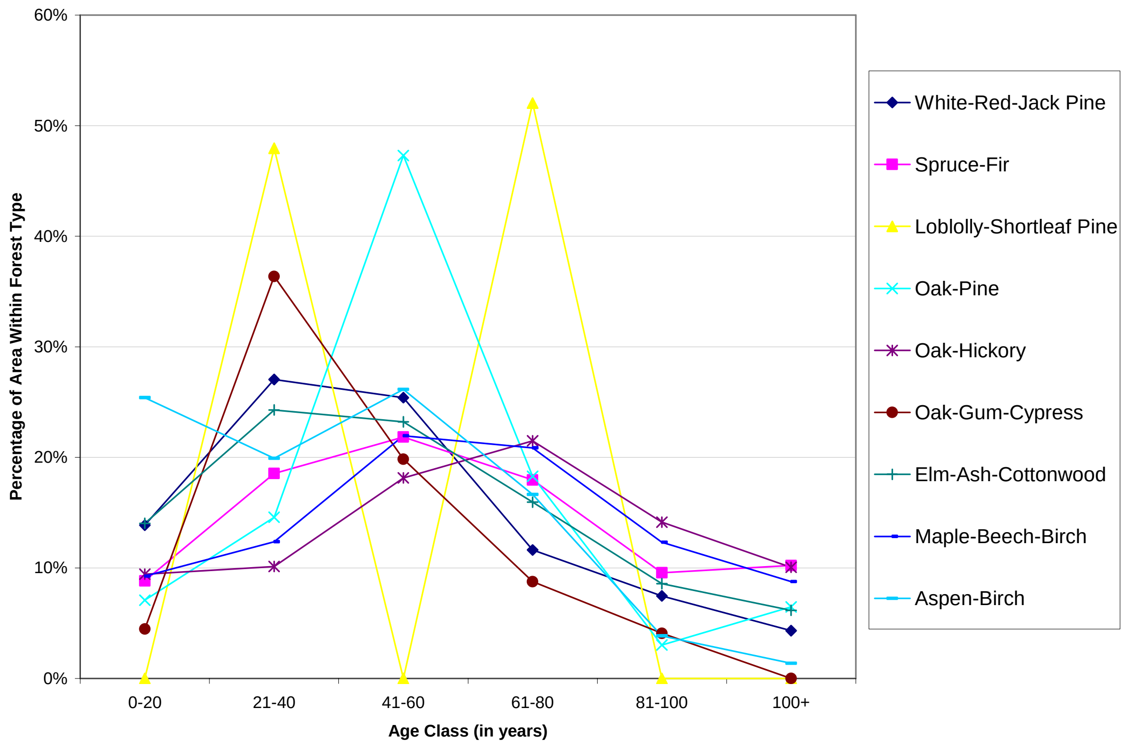

Figure 3. Age-class distribution as a percentage of forested area within forest type for U.S. Great Lakes basin counties
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

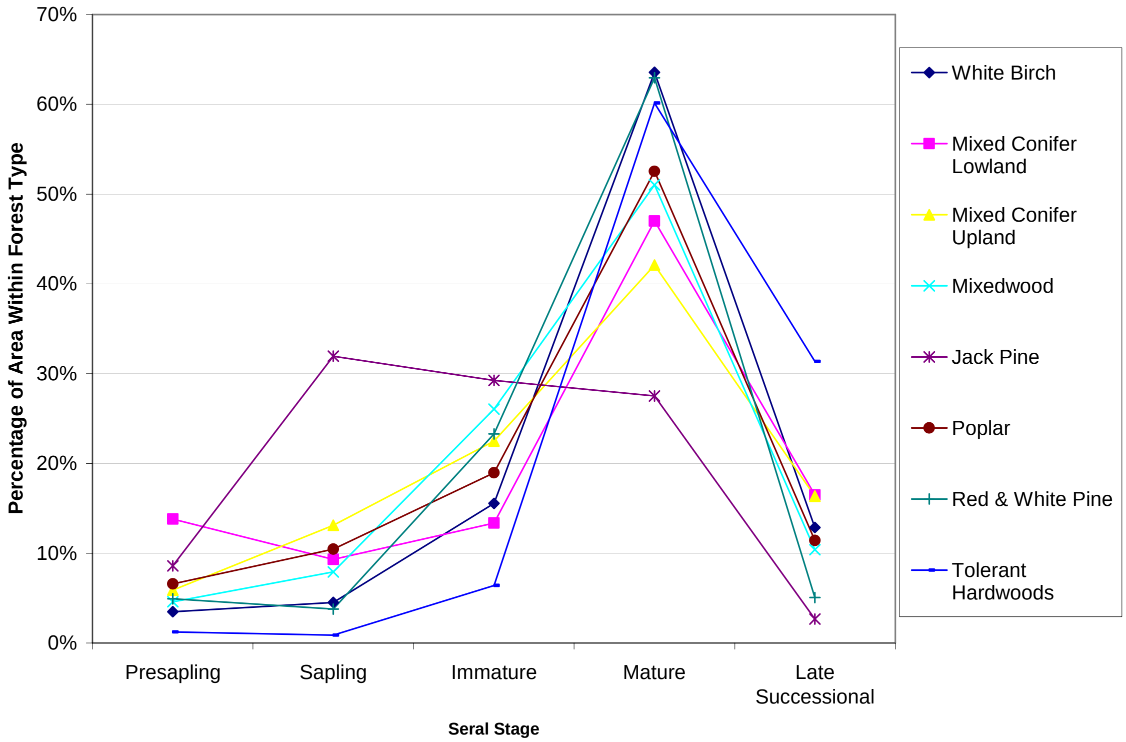

Figure 4. Seral stage distribution as a percentage of forested area within provincial forest type in AOU* portion of Canadian Great Lakes Basin
Caption: * The Area of the Undertaking (AOU) land area represents 72% of total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

Forest Lands – Maintenance of Productive Capacity of Forest Ecosystems
Indicator # 8501

Note: This indicator includes three components and corresponds to Montreal Process Criterion 2, Indicators 10, 11, and 13.

Indicator #8501 Components:
- Component (1) – Area of forest land and area of forest land available for timber production
- Component (2) – Total merchantable volume of growing stock on forest lands available for timber production
- *Component (3) – Annual removal of wood products compared to net growth, or the volume determined to be sustainable (proposed for future analysis; data not presented in this report)*

Overall Assessment

Status:	**Not Assessed**
Trend:	**Undetermined**
Primary Factors Determining Status and Trend	**Additional discussion amongst forestry experts is needed for an assessment determination.**

Lake-by-Lake Assessment

Lake Superior

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	U.S. data by individual lake basin is not available.

Lake Michigan

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	U.S. data by individual lake basin is not available.

Lake Huron

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	U.S. data by individual lake basin is not available.

Lake Erie

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining	U.S. data by individual lake basin is not available.

Status and Trend

Lake Ontario

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	U.S. data by individual lake basin is not available.

Purpose

- To determine the Great Lakes forests' capacity to produce wood products
- To allow for future assessments of changes in productivity over time, which can be representative of social and economic trends affecting management decisions and can also be related to ecosystem health

Ecosystem Objective

To maximize the productive capacity of Great Lakes forests while maintaining the ecosystem's health and sustainability.

State of the Ecosystem

Component (1):

The total area of forest land analyzed in the Great Lakes basin for this report was 35,113,242 hectares. Of this area, about 89% (or a total of 31,194,790 hectares) can be considered as available for timber production, as calculated from U.S. timber land estimates and Canadian productive forests not restricted from harvesting. In the U.S. portion of the basin, the proportion of land available for timber production increased to about 91%, while the value decreased to 86% for the entire Canadian portion of the basin and then rose to 91% for Ontario's managed forests. Complete U.S. data broken down by state and Canadian data broken down by lake basin can be viewed in Tables 1 and 2, respectively.

The amount of forest land available for timber production is directly related to the productive capacity of forests for harvestable goods. This proportion is affected by different types of management activities, which provides an indication of the balance between the need for wood products with the need to satisfy assorted environmental concerns aimed at conservation of biological diversity.

Component (2):

In the analyzed area of Great Lakes basin forests available for timber production, 78% of the total wood volume was merchantable. This percentage of growing stock increased to 92% for the U.S. portion of the basin and decreased to 61% for Ontario's managed forests in the Canadian part of the basin. Complete U.S. data broken down by state and Canadian data broken down by lake basin can be viewed in Tables 3 and 4, respectively.

If the values of net merchantable volume are compared to the total area of forest land available for timber production, a rough estimate of the forests' productive capacity can be obtained. This puts U.S. forests' per-unit-area productivity at a value of 92.7 cubic meters per hectare (m^3/ha), and Canadian forests' at 90.2 (m^3/ha).

Changes in productivity values can be indicative of the ecosystem's health and vigor, as a lowered ratio of merchantable volume to available timber land can suggest reduced growth and ability of trees to absorb nutrients, water and solar energy and increased disease and tree mortality. Further assessment of productive capacity would require additional historical data and analysis by forestry experts.

Component 3:

The growth to removal ratio is often used as a course surrogate for the concept of sustainable production in the U.S. Although exact data for this measure have not been compiled for this report, nationwide U.S. studies have shown that timber growth has exceeded removals for several decades, and Ontario's wood removals on managed timber land is supposedly done within sustainable limits by definition of the forestry practices enacted in those areas.

Pressures

Fluctuating marketplace demands for wood products and increased pressures to reserve forest lands for recreation, conservation of biodiversity and wildlife habitat can affect the volume of timber available for harvest.

Disease and disturbance from fires or other events can also affect productivity capacity.

Management Implications

Timber productivity can be increased through the use of timber plantations and sustainable management of forests available for timber production.

Continued discussion of the meaning of sustainability and how it is affected by wood product removal is crucial to the effectiveness of future management decisions.

Comments from the author(s)

It can be difficult to analyze forest areas and growing stocks for a set moment in time, because inventory time frames can vary. U.S. 2002 RPA data are compiled from a range of different years (1989-1998 for Great Lakes states) depending on when the most recent state inventories were conducted. This issue should diminish as the FIA switches to an annualized survey cycle, and future analyses should therefore incorporate this data.

Although Canadian data are available by watershed, U.S. forest data are compiled by county for this report, so the area of U.S. land analyzed is not necessarily completely within the Great Lakes basin. Corresponding data may be skewed. This factor makes it difficult to represent the data by individual lake basin. Additional GIS analysis of the U.S. raw inventory data would be required to provide forest data by watershed.

Area of timber land in the U.S. is used as a proxy for the net area land available for timber production in U.S. data calculations, but timber land area may include currently inaccessible and inoperable areas or areas where landowners do not have timber production as an ownership objective, and is therefore an overestimation of the net area available for timber production and associated merchantable wood volumes.

Canadian data for growing stock is only available for Ontario's managed forests where Forest Resources Planning Inventories occur. This area is commonly referred to as the Area of the Undertaking (AOU), and only represents 72% of Ontario's total Great Lakes basin land area and 78% of its total forest area. The rest of the Canadian part of the basin is restricted to satellite data capabilities.

Data for annual removal of wood products as compared to net growth is available for Canada and a few of the U.S. Great Lakes states, but was not prepared for the Great Lakes basin at the time of this report. This information should be compiled for future analyses when available, and is an important ratio to monitor over time to ensure that wood harvesting is not reducing the total volume of trees on timber land at larger spatial scales. Unfortunately this value does not add much insight to the detailed ecological attributes of sustainability, and must be analyzed with additional biological components to achieve this indicator's ecosystem objective.

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Table 1. Area of forest land available for timber production* in relationship to total area of forest land in U.S. Great Lakes basin counties
Caption: * Area designated as timber land is used as a proxy for this value and may include inaccessible areas. The presented data should therefore be considered an over-estimation of the net area available for timber production.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

Table 2. Area of forest land available for timber production in relationship to total area of forest land in, A) Canadian Great Lakes basin, and B) the AOU* portion of Ontario

Caption: * The Area of the Undertaking (AOU) land area represents 72% of Ontario's total Great Lakes basin land area and 78% of its total forest area.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

Table 3. Total volume of growing stock* in U.S. Great Lakes basin counties
Caption: * Calculations do not take inaccessibility or inoperability of timber land into account, so resulting values are skewed high
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

Table 4. Total volume of growing stock in Canadian Great Lakes basin*
Caption: * Data only available for Ontario's managed forests (AOU portion of Ontario)
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

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State	Total Area of Forest land (ha)	Area of Forest Land Available for Timber Production* (ha)	% Available for Timber Production*
Illinois	29,322	5,634	19.21%
Indiana	198,351	182,287	91.90%
Michigan	7,802,663	7,533,587	96.55%
Minnesota	3,345,320	2,818,676	84.26%
New York	4,775,982	3,928,686	82.26%
Ohio	742,161	668,190	90.03%
Pennsylvania	223,904	210,992	94.23%
Wisconsin	3,086,921	3,033,084	98.26%
Total	**20,204,626**	**18,381,137**	**90.97%**

Table 1. Area of forest land available for timber production* in relationship to total area of forest land in U.S. Great Lakes basin counties
Caption: * Area designated as timber land is used as a proxy for this value and may include inaccessible areas. The presented data should therefore be considered an over-estimation of the net area available for timber production.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

A) Canadian Great Lakes Basin			
Lake Basin	**Total Area of Forest Land (ha)**	**Net area of Forest Land Available for Timber Production (ha)**	**% Available for Timber Production**
Superior	7,061,238	6,006,356	85.06%
Huron	6,162,419	5,343,401	86.71%
Erie	322,317	291,107	90.32%
Ontario	1,362,643	1,172,788	86.07%
Totals	**14,908,617**	**12,813,653**	**85.95%**
B) AOU* Portion of Ontario			
Lake Basin	**Total Area of AOU's Forest Land (ha)**	**Net area of AOU Forest Land Available for Timber Production (ha)**	**% Available for Timber Production**
Huron	4,710,406	4,227,743	89.75%
Ontario	665,100	611,268	91.91%
Superior	6,227,943	5,749,905	92.32%
Totals	**11,603,450**	**10,588,917**	**91.26%**

Table 2. Area of forest land available for timber production in relationship to total area of forest land in, A) Canadian Great Lakes basin, and B) the AOU* portion of Ontario
Caption: * The Area of the Undertaking (AOU) land area represents 72% of Ontario's total Great Lakes basin land area and 78% of its total forest area.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

State	Total Live Volume* (m^3) on Forest Lands Available for Timber Production	Net Merchantable Volume (m^3) of Timber Products (Growing Stock*)	Volume (m^3) of Non-merchantable Timber Products	% Growing Stock* (of Total Vol. Available for Timber Production)
Illinois	518,577	500,423	18,154	96.50%
Indiana	22,162,859	18,342,594	3,820,265	82.76%
Michigan	829,796,679	754,964,965	74,826,151	90.98%
Minnesota	219,781,880	199,559,859	20,222,021	90.80%
New York	383,181,677	365,098,413	18,083,264	95.28%
Ohio	73,836,032	71,466,897	2,369,136	96.79%
Pennsylvania	25,840,363	24,880,573	959,790	96.29%
Wisconsin	294,891,458	269,125,981	25,765,478	91.26%
Total	**1,850,009,525**	**1,703,939,705**	**146,064,258**	**92.10%**

Table 3. Total volume of growing stock* in U.S. Great Lakes basin counties
Caption: * Calculations do not take inaccessibility or inoperability of timber land into account, so resulting values are skewed high
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2002 Resource Planning Act (RPA) Assessment Database

Lake Basin	Total Volume (m^3) on Forest Lands Available for Timber Production	Net Merchantable Volume (m^3) of Timber Products (Growing Stock)	Volume (m^3) of Non-merchantable Timber Products	% Growing Stock (of Total Vol. Available for Timber Production)
Huron	667,854,390	421,077,634	246,776,756	63.05%
Ontario	114,963,698	72,717,983	42,245,715	63.25%
Superior	787,640,995	461,410,679	326,230,315	58.58%
Totals	**1,570,459,083**	**955,206,296**	**615,252,787**	**60.82%**

Table 4. Total volume of growing stock in Canadian Great Lakes basin*
Caption: * Data only available for Ontario's managed forests (AOU portion of Ontario)
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and NRVIS coverages

Forest Lands – Conservation and Maintenance of Soil and Water Resources
Indicator #8503

Note: This indicator includes two components and corresponds to Montreal Process Criterion 4, Indicator 19

Indicator #8503 Components:

Component (1) – Percent of forested land within riparian zones by watershed and percent of forested land within watershed by Lake basin

Component (2) – Change in area of forest lands certified under sustainable forestry programs in Great Lakes states and Ontario

Overall Assessment

Status:	**Mixed**
Trend:	**Undetermined**
Primary Factors Determining Status and Trend	**Trend information is not available for forested areas at this time. Data for the area of certified forest lands can not be analyzed according to Great Lakes Basin boundaries at this time, but the overall area of certified lands is increasing across the region.**

Lake-by-Lake Assessment

Lake Superior

Status:	Good
Trend:	Undetermined
Primary Factors Determining Status and Trend	A large proportion of the basin's riparian zones and watersheds are forested. Certification data does not exist specific to this individual lake basin.

Lake Michigan

Status:	Mixed
Trend:	Improving, Unchanging, Deteriorating or Undetermined
Primary Factors Determining Status and Trend	Just over half of the basin's riparian zones and watersheds are forested. Certification data does not exist specific to this individual lake basin.

Lake Huron

Status:	Mixed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Over half of the basin's riparian zones and watersheds are forested. Certification data does not exist specific to this individual lake basin.

Lake Erie

Status:	Poor
Trend:	Undetermined
Primary Factors Determining	Only a small portion of the basin's riparian zones and watersheds are forested. Certification data does not exist specific to this individual lake

Status and Trend	basin.

Lake Ontario

Status:	Mixed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Just over half of the basin's riparian zones and watersheds are forested. Certification data does not exist specific to this individual lake basin.

Purpose

- To describe the extent to which Great Lakes basin forests aid in the conservation of the basin's soil resources and protection of water quality.
- To describe the level of Great Lakes states' and Ontario's participation in sustainable forestry certification programs.

Ecosystem Objective

Improved soil and water quality within the Great Lakes basin.

State of the Ecosystem

Component (1):

Forests cover about 61% of the total land and 70% of the riparian zones (defined as the 30 meter buffer around all surface waters) within the Great Lakes basin. This trend of a slightly greater percentage of forested land by riparian zone as opposed to by overall watershed is repeated for every major lake basin for the Great Lakes basin as a whole, (see Figure 2).

The U.S. portion of the basin (including the upper St. Lawrence River watersheds) has forest coverage on 61% of its riparian zones (as of 1992), and the Canadian portion of the basin (excluding the upper St. Lawrence River watersheds) has forest coverage on 76% of its riparian zones (as of 2002), (see Table 1). Lake Superior has the best coverage overall, with forested lands covering 96% of its riparian zones. Lakes Michigan (62%), Huron (74%) and Ontario (61%) all have at least half of their total riparian zones covered with forests, while Lake Erie has only 30% coverage. The percentages of forested riparian zones by watershed are visually represented in Figure 1 and are available summarized by Lake Basin in Figure 2.

While good water quality is generally associated with heavily forested or undisturbed watersheds, (USDA 2004) the existence of a forested buffer near surface water features can also protect soil and water resources despite the land use class present in the rest of the watershed, (Carpenter *et. al* 2003). As the percentage of forest coverage within a riparian zones increases, the amount of runoff and erosion (and therefore nutrient loadings, non-point source pollution and sedimentation) decreases and the capacity of the ecosystem to store water increases. Studies show that heavy forest cover is capable of reducing total runoff by as much as 26% as compared to treeless areas with equivalent land-use conditions, (Sedell, *et. al* 2000) and that riparian forests can reduce nutrient and sediment loadings by 30-90%, (Alliance for the Chesapeake Bay, 2004).

Biodiversity of aquatic species is further maintained in riparian areas with increased forest coverage by an increase in the amount of large woody debris (which affects stream configuration, regulation of organic matter and sediment storage, and aquatic habitat availability) and decreased water temperatures, (Eubanks *et. al* 2002). A study completed in Pennsylvania by Lynch *et. al* in 1985 claimed that complete commercial clear cutting of a riparian zone allowed a 10 ˚*C rise in* stream water temperatures, but the retention of a forested buffer strip only allowed an increase of about 1 ˚*C, (Binkley and MacDonald 1994).* This regulation of water temperatures can be critical to the maintenance of assorted cold-water fisheries like trout.

The lack of consensus on the desired percentage of forested land in the basin or riparian zone (and the desired size of the riparian zone itself) makes it difficult to determine the specific implications of the presented data. Comparisons to historical forest cover in riparian zones and manipulative experiments would be useful for trend establishment.

Component (2):
Sustainable forestry management programs are designed to ensure timber can be grown and harvested in ways that protect the local ecosystem. Participation is often voluntary, but once certification is gained, compliance with management protocols is required. Data from three different certification programs was analyzed for this report. It should be noted that their numbers are not additive, as one area of land can be certified under more than one program at a time.

The area of forest lands certified under the Sustainable Forestry Initiative (SFI®) program increased by 855% from 2003 to 2005 across the Great Lakes region, (see Figure 3). Forest landowners who only elect to enroll in the program, but not go through the formal certification process, often choose to follow the forest management protocols, but are not required to do so until they seek certification. It is therefore possible that a much greater amount of forest lands are being managed according to these sustainable practices than is represented by the given data.

Certification in two other sustainable forestry programs also grew in the U.S. Great Lakes states over the past few years, (see Figure 4). The acres of forest lands certified by the American Tree Farm System (ATFS) rose by 47% between 2004 and 2005. The ATFS is a voluntary certification program for non-industrial, private landowners, and states it's mission as, "To promote the growing of renewable forest resources on private lands while protecting environmental benefits and increasing public understanding of all benefits of productive forestry," (American Forest Foundation, 2004). The Forest Stewardship Council (FSC) is an international body that accredits certification organizations and guarantees their authenticity. Acres of forest lands certified under this organization grew by 50% between 2005 and 2006.

This rise in the area of certified forest lands under all three programs can be interpreted as a greater commitment to sustainable forest management amongst forest industry professionals. The assumption is that continued growth in sustainable management practices will lead to improved soil and water resources in the areas where they are implemented.

Pressures
Component (1): The same pressures exerted on all forest resources also apply here. Development of forest lands to other land use classes (such as developed, agricultural, or pasture) decreases the amount of forest area across watersheds and in riparian zones. Urbanization and

seasonal home construction can specifically impact riparian areas since they are among the most desirable development locations.

Component (2): Participation in sustainable forestry programs can be affected by marketplace popularity. Political climate, status of the economy, and public opinion can all influence forest managers decisions to gain certification.

Management Implications

Component (1): Development of policy directed towards protecting forested lands within riparian zones would help maintain forested buffers near surface waters, thereby leading to a possible improvement of local ecosystem health regardless of the land use classification in the rest of the watershed.

Component (2): Increased reporting of certification data by watershed would make corresponding analyses easier. Greater participation in sustainable forestry certification programs would ensure that all timberland is managed in a sustainable manner.

Comments from the author

Component (1): For the purposes of this report, riparian zone was defined as 30 meters on each side of a surface water feature. Research shows that a forested buffer of this size achieves the widest range of water quality objectives, (Alliance for the Chesapeake Bay, 2004), and is the standard value used in USGS Forestry Service, Northeastern Area. Other sources quote different amounts of forested buffer needed near surface water features to achieve the highest level of soil and water resources protection, ranging anywhere from 8-150 meters from the water’s edge, (Illinois, Indiana, and Ohio Departments of Natural Resources, 2006). The ideal riparian zone size can be affected by a variety of factors such as stream, vegetation and soil type, geomorphology, slope of land, and season, (Eubanks *et. al*, 2002).

The resolution of the US landcover dataset used in this analysis was coarse enough to cause slight inaccuracies, but the data was determined as suitable for summarization at the watershed scale.

Additional research of existing literature would be helpful in further quantifying the effects of riparian forests on erosion, run-off, water temperatures, and nutrient and pollutant storage. Although specific studies have been done on these topics, the differences in metrics and sample locations complicate comparisons for the Great Lakes Basin.

Component (2): In subsequent analyses, data should be collected for the percent of forested riparian zones that lie within areas also certified in sustainable forestry programs. Presently, certification data cannot be analyzed by watershed or riparian area, and is therefore less useful for any analyses other than assessment of changing trends in the programs’ utilization.

Expanding this component to include rates of compliance with Forestry Best Management Practices (BMPs) would provide valuable information for additional analyses. While certification in sustainable forestry programs often includes the implementation of BMPs, not all forest lands managed according to BMPs are also certified. Forestry BMPs have been developed in all Great

Lakes states and provinces, so obtaining the relevant audit data would provide a greater and more detailed information base relating to the conservation of forest, soil and water resources.

Many BMPs are directed at reducing non-point source pollution and some states even have monitoring data relating to issues such as water quality. For example, Wisconsin's Forestry Best Management Practices for Water Quality Report stated that, when BMPs were correctly applied to areas where they were needed, 96% of the monitored area showed no adverse impact on water quality, (Breunig *et. al* 2003). It is generally accepted that this trend exists in other states as well. For although individual states' BMPs may differ, studies have shown that their correct implementation results in effective protection of water quality overall.

Acknowledgments
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USDA Forest Service, Northeastern Area State and Private Forestry, Information Management and Analysis. 2006. Forest land by Watershed. Data supplied by Rebecca Whitney, USDA Forest Service, rwhitney@fs.fed.us .

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Caption for Table 1: * = Including Upper St. Lawrence, ** = Not including Upper St. Lawrence

Data Sources:

US data: USDA Forest Service, Northeastern Area State and Private Forestry, Information Management and Analysis. 2005. Riparian Area Land Cover Types based on the 1992 National Land Cover Dataset. Lake Basin boundaries refined by U.S. EPA, Great Lakes National Program Office.

Canadian data: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories and NRVIS watershed coverage (1994).

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Figure 1. Percent Forested Land within Riparian Zones by Watershed in the Great Lakes Basin. Area is technically part of the St. Lawrence River drainage, but included in the Great Lakes basin by definition in the Clean Water Act and Great Lakes Water Quality Agreement.
Data Sources:
USGS National Hydrography Dataset (1999); USGS 1992 National Cover Dataset (1999); USGS 8-digit Watersheds (Hydrologic Unit Code; 1994); Riparian Areas created by the USDA Forest Service North Central Research Station (2005).
Ontario Ministry of Natural Resources – NRVIS Watershed Coverage (1994); Landcover (2002); Riparian Areas created by Forest Evaluation Section
Map data from USDA Forest Service, Information Management and Analysis Group, Durham, NH and U.S. EPA, Great Lakes National Program Office.
Map created by U.S. EPA, Great Lake National Program Office, Technical Assistance and Analysis Branch

Figure 2. Percent of Land Forested within Great Lakes Watersheds and Riparian Zones by Lake Basin.
Caption for figure 2: * = Upper St. Lawrence data only available for U.S.
Data Sources:
US data: USDA Forest Service, Northeastern Area State and Private Forestry, Information Management and Analysis. 2005. Riparian Area Land Cover Types based on the 1992 National Land Cover Dataset. Lake Basin boundaries refined by U.S. EPA, Great Lakes National Program Office.
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Figure 3. Forest Lands Certified Under SFI in the Great Lakes region (U.S. States and province of Ontario), 2003-2005.
Data Source:
Personal communication with Jason Metnick, SFI Label and Licensing, Sustainable Forestry Board, 2006.

Figure 4. Forest Lands Certified Under ATFS and FSC in the Great Lakes States (U.S. only).
Data provided by Sherri Wormstead of the USDA Forestry Service (swormstead@fs.fed.us) using following sources:
FSC data originally obtained from Will Price, the Pinchot Institute and verified and edited from FSC online database: http://www.fscus.org/certified_companies/
ATFS data source: Program Statistics (January 2005) (provided by Emily Chan, American Forest Foundation, by e-mail on 11-4-2005)

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Basin	U.S. (1992)		Ontario (2002)	
	% Forested (Entire Watershed)	% Forested (Riparian Areas)	% Forested (Entire Watershed)	% Forested (Riparian Areas)
Lake Superior	87.73%	88.44%	98.60%	98.05%
Lake Michigan	51.54%	61.90%		
Lake Huron	55.07%	54.28%	74.65%	77.04%
Lake Erie	22.90%	36.24%	14.30%	19.95%
Lake Ontario	52.15%	63.25%	49.99%	59.28%
St. Lawrence River	84.10%	87.03%		
Totals	**53.13%***	**60.43%***	**73.05%****	**75.67%****

Table 1. Percent of Land Forested within U.S. and Canadian Great Lakes Watersheds and Riparian Zones by Lake Basin.
Caption for Table 1: * = Including Upper St. Lawrence, ** = Not including Upper St. Lawrence
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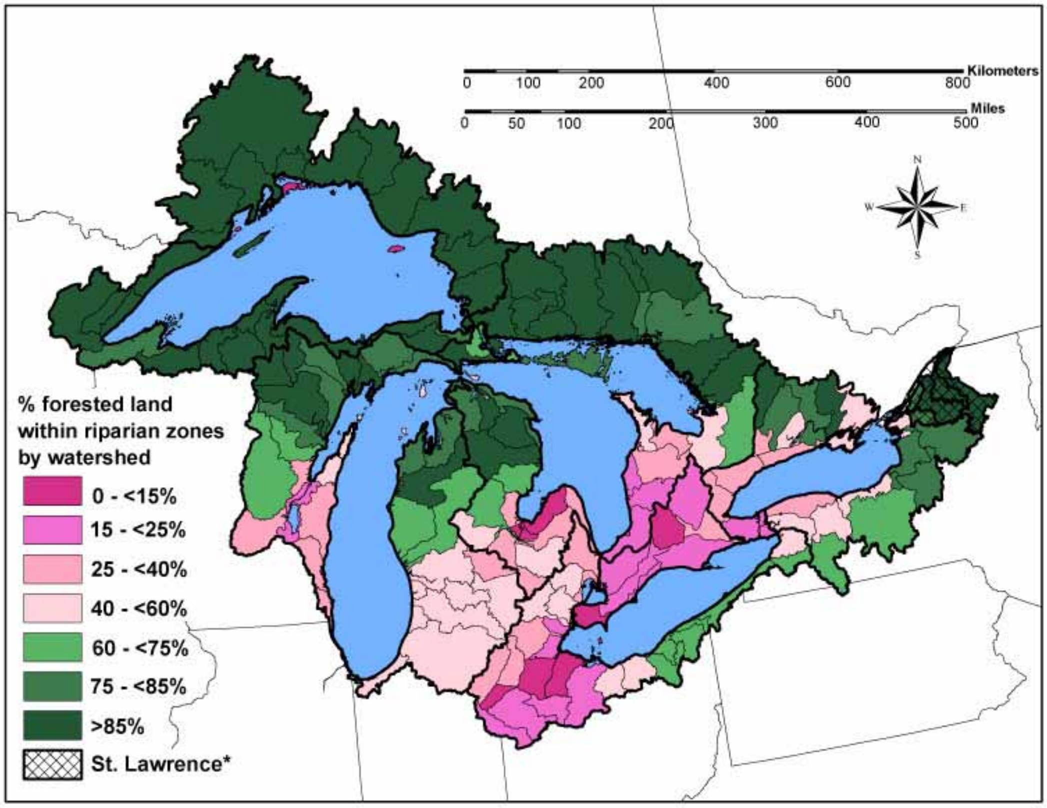

Figure 1. Percent Forested Land within Riparian Zones by Watershed in the Great Lakes Basin. *The area within the St. Lawrence River drainage does not actually drain into the Great Lakes basin, but is still included in the Great Lakes basin by definition in the Clean Water Act and the Great Lakes Water Quality Agreement.
Data Sources:
USGS National Hydrography Dataset (1999); USGS 1992 National Cover Dataset (1999); USGS 8-digit Watersheds (Hydrologic Unit Code; 1994); Riparian Areas created by the USDA Forest Service North Central Research Station (2005).
Ontario Ministry of Natural Resources – NRVIS Watershed Coverage (1994); Landcover (2002); Riparian Areas created by Forest Evaluation Section
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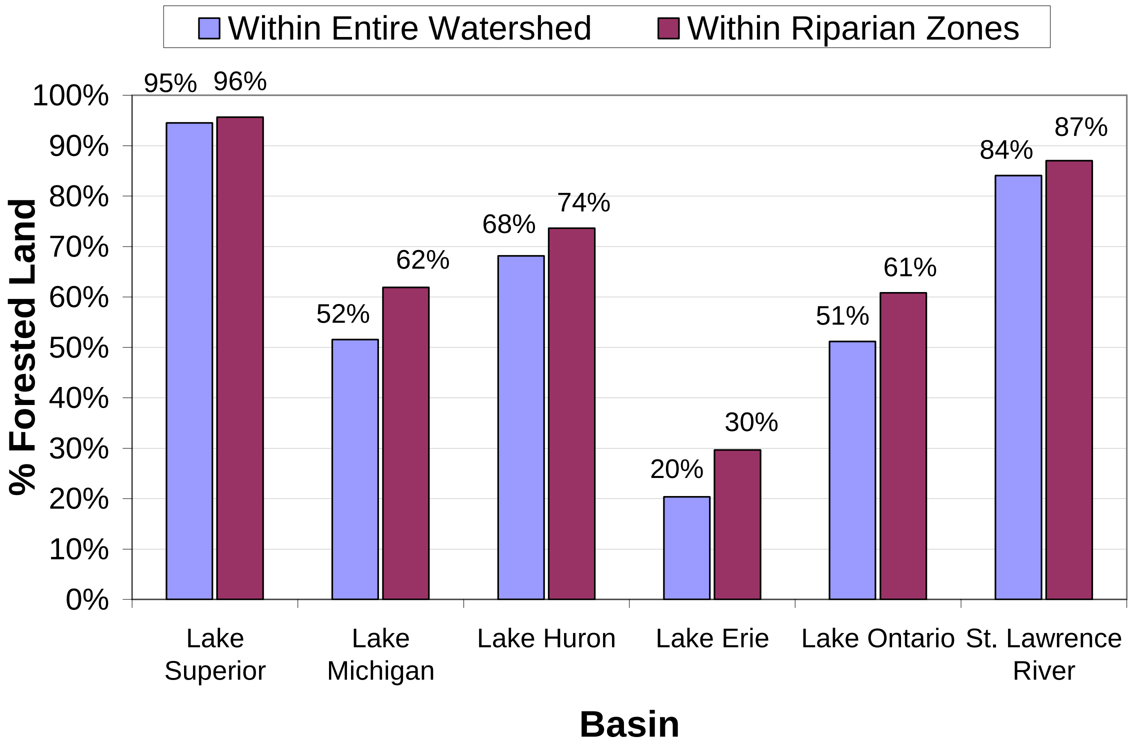

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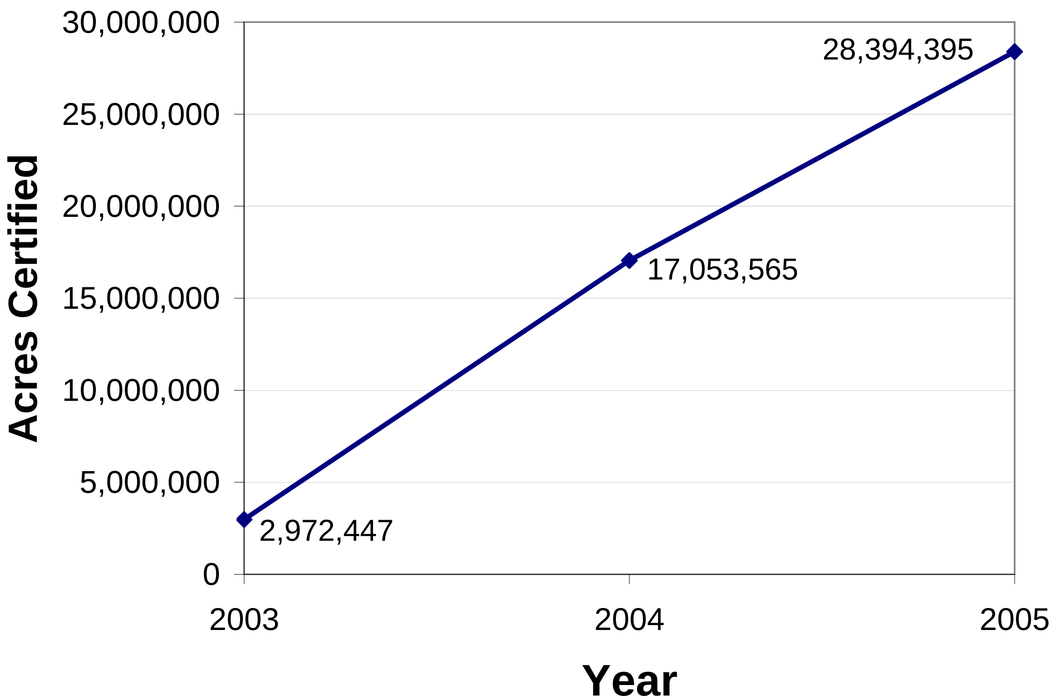

Figure 3. Forest Lands Certified Under SFI in the Great Lakes region (U.S. States and province of Ontario), 2003-2005.
Data Source:
Personal communication with Jason Metnick, SFI Label and Licensing, Sustainable Forestry Board, 2006.

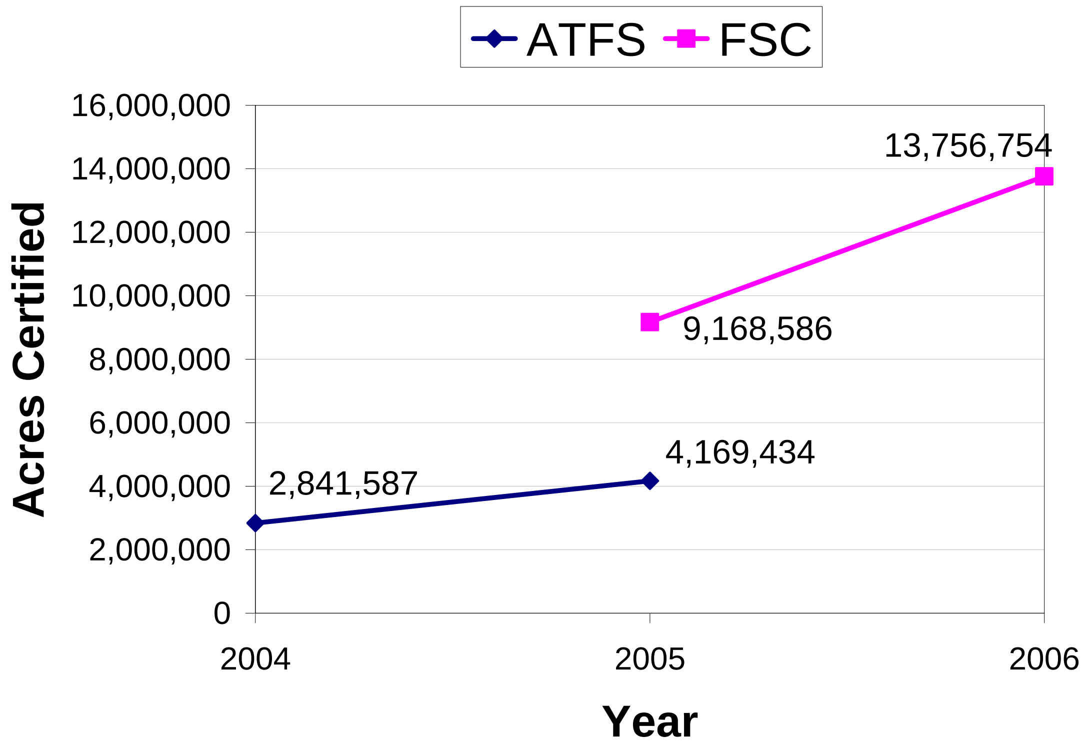

Figure 4. Forest Lands Certified Under ATFS and FSC in the Great Lakes States (U.S. only). Data provided by Sherri Wormstead of the USDA Forestry Service (swormstead@fs.fed.us) using following sources:
FSC data originally obtained from Will Price, the Pinchot Institute and verified and edited from FSC online database: http://www.fscus.org/certified_companies/
ATFS data source: Program Statistics (January 2005) (provided by Emily Chan, American Forest Foundation, by e-mail on 11-4-2005)

Acid Rain

Indicator #9000

Assessment: Mixed, Improving

Purpose

- To assess the pH levels in precipitation;
- To assess the critical loads of sulfate to the Great Lakes basin; and
- To infer the efficacy of policies to reduce sulfur and nitrogen acidic compounds released into the atmosphere.

Ecosystem Objective

The 1991 Canada-U.S. Air Quality Agreement (Air Quality Agreement) pledges the two nations to reduce the emissions of acidifying compounds by approximately 40% relative to 1980 levels. The 1998 Canada-Wide Acid Rain Strategy for Post-2000 intends to further reduce emissions to the point where deposition containing these compounds does not adversely impact aquatic and terrestrial biotic systems.

State of the Ecosystem

Background

Acid rain, more properly called "acidic deposition", is caused when two common air pollutants, sulfur dioxide (SO_2) and nitrogen oxides (NO_x), are released into the atmosphere, react and mix with atmospheric moisture and return to the earth as acidic rain, snow, fog or particulate matter. These pollutants can be carried over long distances by prevailing winds, creating acidic precipitation far from the original source of the emissions. Environmental damage typically occurs where local soils and/or bedrock do not effectively neutralize the acid.

Lakes and rivers have been acidified by acid rain, directly or indirectly causing the disappearance of invertebrates, many fish species, waterbirds and plants. Not all lakes exposed to acid rain become acidified, however. Lakes located in terrain that is rich in calcium carbonate (e.g. on limestone bedrock) are able to neutralize acidic deposition. Much of the acidic precipitation in North America falls in areas around and including the Great Lakes basin. Northern Lakes Huron, Superior and Michigan, their tributaries and associated small inland lakes are located on the geological feature known as the Canadian Shield. The Shield is primarily composed of granitic bedrock and glacially derived soils that cannot easily neutralize acid, thereby resulting in the acidification of many small lakes (particularly in northern Ontario and the northeastern U.S.). The five Great Lakes are so large that acidic deposition has little effect on them directly. Impacts are mainly felt on vegetation and inland lakes in acid-sensitive areas.

A recent report published by the Hubbard Brook Research Foundation has demonstrated that acid deposition is still a significant problem and has had a greater environmental impact than previously thought (Driscol *et al*. 2001). For example, acid deposition has altered soils in the northeastern U.S. through the accelerated leaching of base cations, the accumulation of nitrogen and sulfur, and an increase in concentrations of aluminum in soil waters. Acid deposition has also contributed to the decline of red spruce trees and sugar maple trees in the eastern U.S. Similar observations have been made in eastern Canada (Ontario and eastward) and are reported in the 2004 Canadian Acid Deposition Science Assessment (Environment Canada 2005). The assessment confirms that although levels of acid deposition have declined in eastern Canada over the last two decades, approximately 21% of the mapped area currently receives levels of acid rain in excess of what the region can handle, and 75% of the area is at potential risk of damage should all nitrogen deposition become acidifying, i.e. aquatic and terrestrial ecosystems become nitrogen saturated.

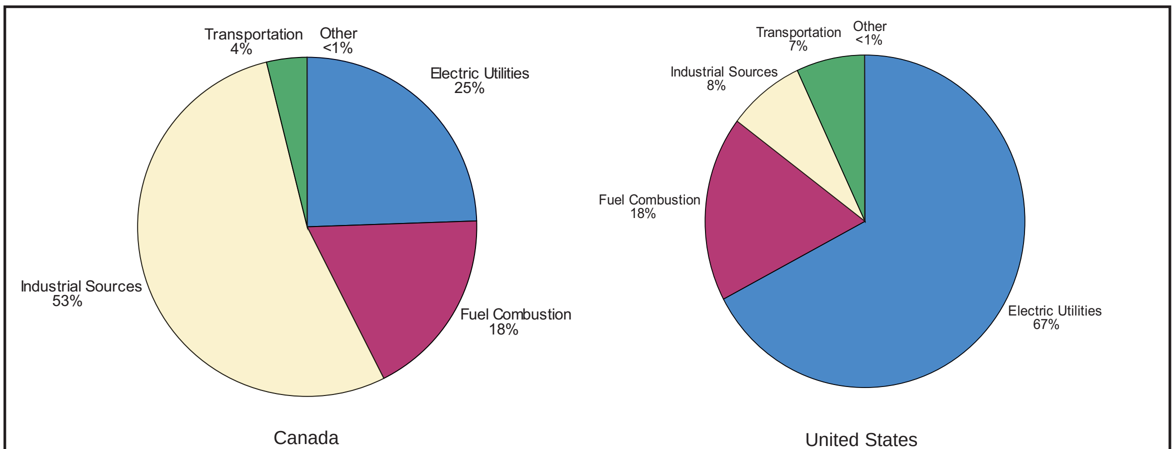

Figure 1. Sources of Sulfur Dioxide Emissions in Canada and the U.S. (1999)
Source: Figure 4 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf and Environment Canada 1999 National Pollutant Release Inventory Data and U.S. Environmental Protection Agency 1999 National Emissions Inventory Documentation and Data

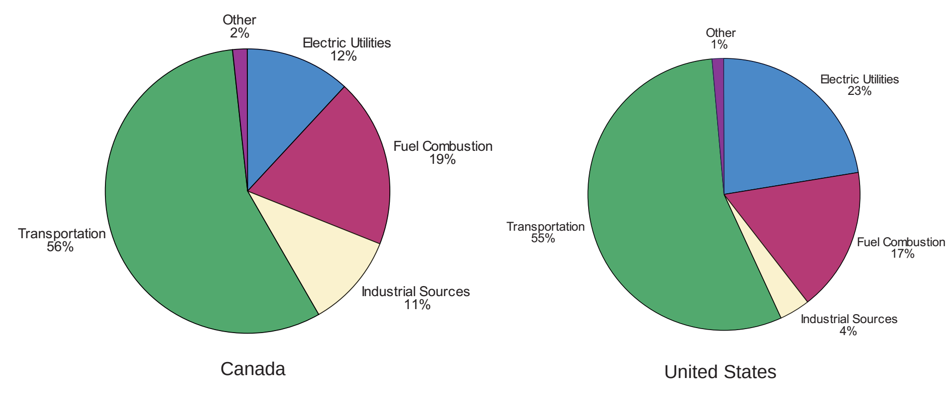

Figure 2. Sources of Nitrogen Oxides Emissions in Canada and the U.S. (1999)
Source: Figure 6 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf and Environment Canada 1999 Pollutant Release Inventory Data and U.S. Environmental Protection Agency 1999 National Emissions Inventory Documentation and Data

By 2000, Canadian NO_x emissions were reduced by more than 100,000 tonnes below the forecast level of 970,000 tonnes (established by Acid Rain Annex) at power plants, major combustion sources, and smelting operations. In the U.S., reductions in NO_x emissions have significantly surpassed the 2 million ton reduction for stationary and mobile sources mandated by the Clean Air Act Amendments of 1990. Under the Acid Rain Program alone, NO_x emissions for all the affected sources in 2002 were 4.5 million tons, about 33% lower than emissions from the sources in 1990. Overall NO_x emissions decreased by about 12% in the U.S. from 1993 to 2002 and remained relatively constant in Canada since 1990, but they are projected to decrease considerably in both countries by 2010. For additional information on SO_2 and NO_x emission reductions, including sources outside the Acid Rain Program, please refer to indicator report #4176 Air Quality.

Sulfur Dioxide and Nitrous Oxides Emissions Reductions

SO_2 emissions come from a variety of sources. The most common releases of SO_2 in Canada are industrial processes such as nonferrous mining and metal smelting. In the United States, electrical utilities constitute the largest emissions source (Figure 1). The primary source of NO_x emissions in both countries is the combustion of fuels in motor vehicles, with electric utilities and industrial sources also contributing (Figure 2).

Canada is committed to reducing acid rain in its south-eastern region to levels below those that cause harm to ecosystems – a level commonly called the “critical load” - while keeping other areas of the country (where acid rain effects have not been observed) clean. In 2000, total SO_2 emissions in Canada were 2.4 million tonnes, which is about 23% below the national cap of 3.2 million tonnes reiterated under Annex 1 (the Acid Rain Annex) of the Air Quality Agreement. Emissions in 2000 also represent a 50% reduction from 1980 emission levels. The seven easternmost provinces’ 1.6 million tonnes of emissions in 2000 were 29% below the eastern Canada cap of 2.3 million tonnes reiterated under the Acid Rain Annex.

In 2002, all participating sources of the U.S. Environmental Protection Agency’s Acid Rain Program (Phase I & II) achieved a total reduction in SO_2 emissions of about 35% from 1990 levels, and 41% from 1980 levels. The Acid Rain Program now affects approximately 3,000 fossil-fuel power plant units. These units reduced their SO_2 emissions to 10.19 million tons in 2002, about 4% lower than 2001 emissions. Full implementation of the program in 2010 will result in a permanent national emissions cap of 8.95 million tons, representing about a 50% reduction from 1980 levels.

Figure 3 illustrates the trends in SO_2 emission levels in Canada and the United States measured from 1980 to 2000 and predicted through 2010. Overall, a 38% reduction in SO_2 emissions is projected in Canada and the United States from 1980 to 2010. In the U.S., the reductions are mainly due to controls on electric utili-

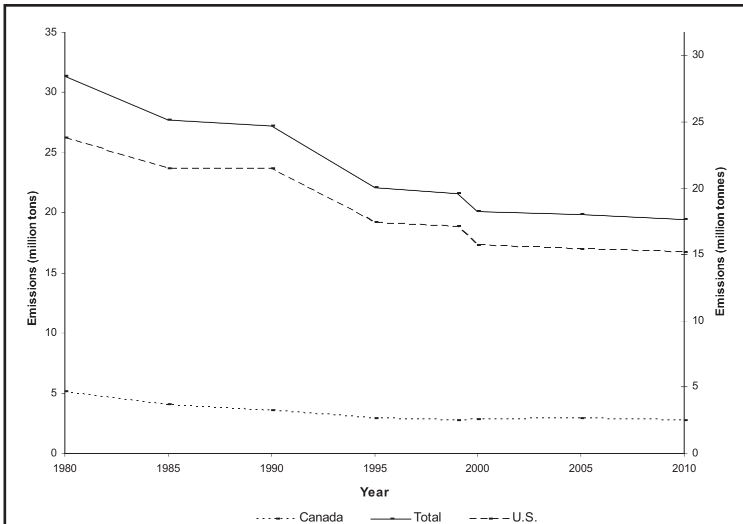

Figure 3. Canada-U.S. sulfur dioxide emissions, 1980-2010
Source: Figure 3 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf and U.S. Environmental Protection Agency. Projection year emissions data. http://www.epa.gov/otaq/models/hd2007/r00020.pdf

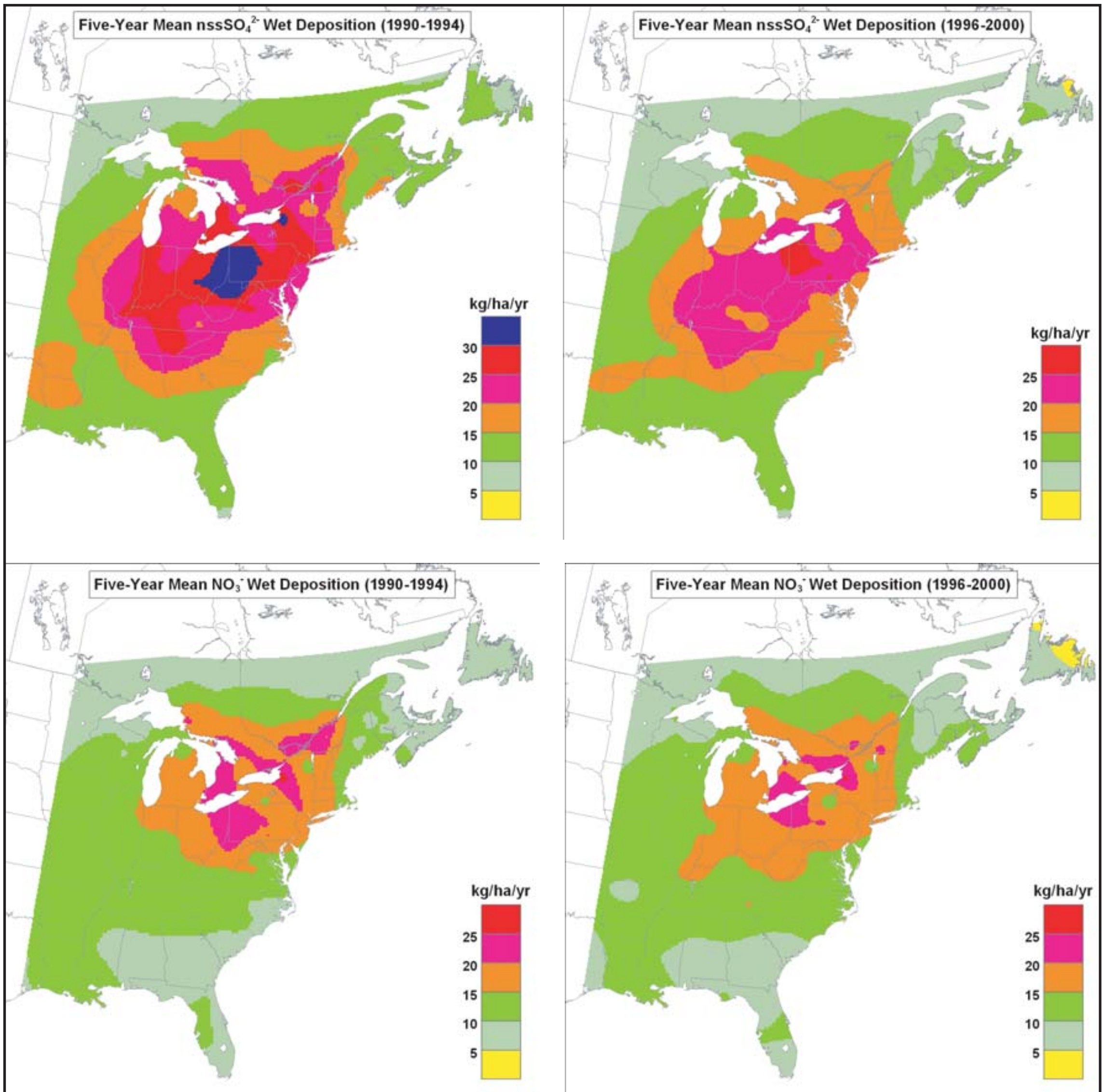

Figure 4. Five-year mean patterns of wet non-sea-salt-sulfate ($nssS0_4^{2-}$) and wet nitrate deposition for the periods 1990-1994 and 1996-2000.
Source: Figures 9 through 12 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf, and Jeffries, D.S., T.G., Brydges, P.J. Dillion and W. Keller. 2003. Monitoring the results of Canada/U.S.A. acid rain control programs: some lake responses. J. of Environmental Monitoring and Assessment. 88:3-20

ties under the Acid Rain Program and the desulphurization of diesel fuel under Section 214 of the 1990 Clean Air Act Amendments. In Canada, reductions of SO_2 are mainly attributed to reductions from the non-ferrous mining and smelting sector, and electric utilities as part of the 1985 Eastern Canada Acid Rain Program that was completed in 1994. Further SO_2 reductions will be achieved through the implementation of the Canada-Wide Acid Rain Strategy.

Figure 4 compares wet sulfate deposition (kilograms sulfate per hectare per year) over eastern North America before and after the 1995 Acid Rain Program Phase I emission reductions to assess whether the emission decreases had an impact on large-scale wet deposition. The five-year average sulfate wet deposition pattern for the years 1996-2000 is considerably reduced from that for the five-year period prior to the Phase I emission reductions (1990-1994). For example, the large area that received 25 to 30 kg/ha/yr of sulfate wet deposition in the 1990-1994 period had almost disappeared in the1996-2000 period. The shrinkage of the wet deposition pattern between the two periods strongly suggests that the Phase I emission reductions were successful at reducing the sulfate wet deposition over a large section of eastern North America. Monitoring data from 2000 through 2002 indicate that wet sulfate deposition continued to decrease, probably as a result of Phase II of the Acid Rain Program. However, if SO_2 emissions remain relatively constant after the year 2000, as predicted (Figure 3), it is unlikely that sulfate deposition will change considerably in the coming decade. Sulfate deposition models predict that in 2010, following implementation of the Phase II acid rain program, critical loads for aquatic ecosystems in eastern Canada will still be exceeded over an area of approximately 800,000 km^2.

A somewhat different story occurs for nitrate wet deposition.

The spatial patterns shown in Figure 4 are approximately the same before and after the Phase I emission reductions. This suggests that the minimal reductions in NO_x emissions after Phase I resulted in minimal changes to nitrate wet deposition over eastern North America.

Pressures

As the human population within and outside the basin continues to grow, there will be increasing demands on electrical utility companies and natural resources and increasing numbers of motor vehicles. Considering this, reducing nitrogen deposition is becoming more and more important, as its contribution to acidification may soon outweigh the benefits gained from reductions in sulfur dioxide emissions.

Management Implications

The effects of acid rain can be seen far from the source of SO_2 and NO_x generation, so the governments of Canada and the United States are working together to reduce acid emissions. The 1991 Canada - United States Air Quality Agreement addresses transboundary pollution. To date, this agreement has focused on acidifying pollutants and significant steps have been made in the reduction of SO_2 emissions. However, further progress in the reduction of acidifying pollutants, including NO_x, is required.

In December 2000, Canada and the United States signed Annex III (the Ozone Annex) to the Air Quality Agreement. The Ozone Annex committed Canada and the U.S. to aggressive emission reduction measures to reduce emissions of NO_x and volatile organic compounds. (For more information on the Ozone Annex, please refer to Report # 4176 Air Quality).

The 1998 Canada-wide Acid Rain Strategy for Post-2000 provides a framework for further actions, such as establishing new SO_2 emission reduction targets in Ontario, Quebec, New Brunswick and Nova Scotia. In fulfillment of the Strategy, each of these provinces has announced a 50% reduction from its existing emissions cap. Quebec, New Brunswick and Nova Scotia are committed to achieving their caps by 2010, while Ontario committed to meet its new cap by 2015.

Since the last State of the Lakes Ecosystem Conference (SOLEC) report, there has been increasing interest in both the public and private sector in a multi-pollutant approach to reducing air pollution. On March 10, 2005, the U.S. Environmental Protection Agency (USEPA) issued the Clean Air Interstate Rule (CAIR), a rule that will achieve the largest reduction in air pollution in more than a decade. Through a cap-and-trade approach, CAIR will permanently cap emissions of SO_2 and NO_x across 28 eastern states and the District of Columbia. When fully implemented, CAIR is expected to reduce SO_2 emissions in these states by 73% and NO_x emissions by 61% from 2003 levels.

The Clear Skies Initiative, originally proposed by U.S. President George W. Bush in February 2002, would require a similar level of SO_2 and NO_x reductions as CAIR. Because Clear Skies would be enacted through legislation rather than regulation, it would be a more efficient, long-term mechanism to achieve multi-pollutant reductions on a national scale. The USEPA is committed to working with Congress to pass this legislation. However, if Clear Skies is not passed, CAIR still remains in effect.

Acknowledgments

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Kerri Timoffee, Manager, Acid Rain Program, Environment Canada, Gatineau, QC; and
Todd Nettesheim, Great Lakes National Program Office, United States Environmental Protection Agency, Chicago, IL.

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Authors' Commentary

While North American SO_2 emissions and sulfate deposition levels in the Great Lakes basin have declined over the past 10 to 15 years, rain is still too acidic throughout most of the Great Lakes region, and many acidified lakes do not show recovery (increase in water pH or alkalinity). Empirical evidence suggests that there are a number of factors acting to delay or limit the recovery response, e.g. increasing importance of nitrogen-based acidification, soil depletion of base cations, mobilization of stored sulfur, climatic influences, etc. Further work is needed to quantify the additional reduction in deposition needed to overcome these limitations and to accurately predict the recovery rate.

Last Updated

State of the Great Lakes 2005

Non-native Species – Aquatic
Indicator #9002

Overall Assessment

Status:	**Poor**
Trend:	**Deteriorating**
Primary Factors Determining Status and Trend	**NIS continue to be discovered in the Great Lakes. Negative impacts of established invaders persist and new negative impacts are becoming evident**

Lake-by-Lake Assessment
Lake Superior

Status:	Fair
Trend:	Unchanging
Primary Factors Determining Status and Trend	Lake Superior is the site of most ballast water discharge in the Great Lakes, but supports relatively few NIS. This is due at least in part to less hospitable environmental conditions.

Lake Michigan

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Established invaders continue to exert negative impacts on native species. *Diporeia* populations are declining.

Lake Huron

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Established invaders continue to exert negative impacts on native species. *Diporeia* populations are declining.

Lake Erie

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Established invaders continue to exert negative impacts on native species. A possible link exists between waterfowl deaths due to botulism and established NIS (round goby and dreissenid mussels)

Lake Ontario

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Native *Diporeia* populations are declining in association with quagga mussel expansion. Condition and growth of lake whitefish, whose primary food source is *Diporeia*, are declining. A possible link exists between waterfowl deaths due to botulism and established NIS (round goby and dreissenid mussels).

Purpose
•To assess the presence, number and distribution of nonindigenous species (NIS) in the Laurentian Great Lakes; and
•To aid in the assessment of the status of biotic communities, because nonindigenous species can alter both the structure and function of ecosystems.

Ecosystem Objective
The goal of the U.S. and Canada Great Lakes Water Quality Agreement is, in part, to restore and maintain the biological integrity of the waters of the Great Lakes ecosystem. Minimally, extinctions and unauthorized introductions must be prevented to maintain biological integrity.

State of the Ecosystem
Background
Nearly 10% of NIS introduced to the Great Lakes have had significant impacts on ecosystem health, a percentage consistent with findings in the United Kingdom (Williamson and Brown 1986) and in the Hudson River of North America (Mills *et al*. 1997). In the Great Lakes, transoceanic ships are the primary invasion vector. Other vectors, such as canals and private sector activities, however, are also utilized by NIS with potential to harm biological integrity.

Status of NIS
Human activities associated with transoceanic shipping are responsible for over one-third of NIS introductions to the Great Lakes (Figure 1). Total numbers of NIS introduced and established in the Great Lakes have increased steadily since the 1830s (Figure 2a). Numbers of ship-introduced NIS, however, have increased exponentially during the same time period (Figure 2b). Release of contaminated ballast water by transoceanic ships has been implicated in over 70% of faunal NIS introductions to the Great Lakes since the opening of the St. Lawrence Seaway in 1959 (Grigorovich *et al*. 2003).

During the 1980s, the importance of ship ballast water as a vector for NIS introductions was recognized, finally prompting ballast management measures in the Great Lakes. In the wake of Eurasian ruffe and zebra mussel introductions, Canada introduced voluntary ballast exchange guidelines in 1989 for ships declaring "ballast on board" (BOB) following transoceanic voyages, as recommended by the Great Lakes Fishery Commission and the International Joint Commission. In 1990, the United States Congress passed the Nonindigenous Aquatic Nuisance Prevention and Control Act, producing the Great Lakes' first ballast exchange and management regulations in May of 1993. The National Invasive Species Act (NISA) followed in 1996, but this act expired in 2002. A stronger version of NISA entitled the Nonindigneous Aquatic Invasive Species Act has been drafted and awaits Congressional reauthorization.

Contrary to expectations, the reported invasion rate has increased following initiation of voluntary guidelines in 1989 and mandated regulations in 1993 (Grigorovich *et al*. 2003, Holeck *et al*. 2004). However, >90% of transoceanic ships that entered the Great Lakes during the 1990s declared "no ballast on board" (NOBOB, Colautti *et al*. 2003; Grigorovich *et al*. 2003; Holeck *et al*. 2004) (Figure 3) and were not required to exchange ballast, although their tanks contained residual sediments and water that would be discharged in the Great Lakes. Recent studies suggest that the Great Lakes may vary in vulnerability to invasion in space and time. Lake Superior receives a disproportionate number of discharges by both BOB and NOBOB ships, yet it has sustained surprisingly few initial invasions (Figure 4); conversely, the waters connecting lakes Huron and Erie are an invasion 'hotspot' despite receiving disproportionately few ballast discharges (Grigorovich *et al*. 2003). Ricciardi (2001) suggests that some invaders (such as *Dreissena* spp.) may facilitate the introduction of coevolved species such as round goby and the amphipod *Echinogammarus*.

Other vectors, including canals and the private sector, continue to deliver NIS to the Great Lakes and may increase in relative importance in the future. Silver and bighead carp escapees from southern U.S. fish farms have been sighted below an electric dispersal barrier in the Chicago Sanitary and Ship Canal, which connects the Mississippi River and Lake Michigan. The prototype barrier was activated in April 2002, to block the transmigration of species between the Mississippi River system and the Great Lakes basin. The U.S. Army Corps of Engineers (partnered by the State of Illinois) completed construction of a second, permanent barrier in 2005.

Second only to shipping, unauthorized release, transfer, and escape have introduced NIS into the Great Lakes. Of particular concern are private sector activities related to aquaria, garden ponds, baitfish, and live food fish markets. For example, nearly a million Asian carp, including bighead and black carp, are sold annually at fish markets within the Great Lakes basin. Until recently, most of these fish were sold live. All eight Great Lakes states and the province of Ontario now have some restriction on the sale of live Asian carp. Enforcement of many private transactions, however, remains a challenge. The U.S. Fish and Wildlife Service is considering listing several Asian carp as nuisance species under the Lacey Act, which would prohibit interstate transport. Finally, there are currently numerous shortcomings in legal safeguards relating to commerce in exotic live fish as identified by Alexander (2003) in Great Lakes and Mississippi River states, Quebec, and Ontario. These include: express and de facto exemptions for the aquarium pet trade; de facto exemptions for the live food fish trade; inability to proactively enforce import bans; lack of inspections at aquaculture facilities; allowing aquaculture in public waters; inadequate triploidy (sterilization) requirements; failure to regulate species of concern, e.g., Asian carp; regulation through "dirty lists" only, e.g., banning known nuisance species; and failure to regulate transportation.

Pressures

NIS have invaded the Great Lakes basin from regions around the globe (Figure54), and increasing world trade and travel will elevate the risk that additional species (Table 1) will continue to gain access to the Great Lakes. Existing connections between the Great Lakes watershed and systems outside the watershed, such as the Chicago Sanitary and Ship Canal, and growth of industries such as aquaculture, live food markets, and aquarium retail stores will also increase the risk that NIS will be introduced.

Changes in water quality, global climate change, and previous NIS introductions also may make the Great Lakes more hospitable for the arrival of new invaders. Evidence indicates that newly invading species may benefit from the presence of previously established invaders. That is, the presence of one NIS may facilitate the establishment of another (Ricciardi 2001). For example, round goby and *Echinogammarus* have benefited from previously established zebra and quagga mussels. In effect, dreissenids have set the stage to increase the number of successful invasions, particularly those of co-evolved species in the Ponto-Caspian assemblage.

Management Implications

Researchers are seeking to better understand links between vectors and donor regions, the receptivity of the Great Lakes ecosystem, and the biology of new invaders in order to make recommendations to reduce the risk of future invasion. To protect the biological integrity of the Great Lakes, it is essential to closely monitor routes of entry for NIS, to introduce effective safeguards, and to quickly adjust safeguards as needed. Invasion rate may increase if positive interactions involving established NIS or native species facilitate entry of new NIS. Ricciardi (2001) suggested that such a scenario of "invasional meltdown" is occurring in the Great Lakes, although Simberloff (2006) cautioned that most of these cases have not been proven.

To be effective in preventing new invasions, management strategies must focus on linkages between NIS, vectors, and donor and receiving regions. Without measures that effectively eliminate or minimize the role of ship-borne and other, emerging vectors, we can expect the number of NIS in the Great Lakes to continue to rise, with an associated loss of native biodiversity and an increase in unpredicted ecological disruptions.

Comments from the author(s)

Lake by lake assessment should include Lake St. Clair and connecting channels (Detroit River, St. Clair River). Species first discovered in these waters were assigned to Lake Erie for the purposes of this report.

Acknowledgments

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Source: Mills *et al*. 1993; Ricciardi 2001; Grigorovich *et al*. 2003; Ricciardi 2006

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Figure 4. Lake of first discovery for NIS established in the Great Lakes basin since the 1830s. Discoveries in connecting waters between Lakes Huron, Erie and Ontario were assigned to the downstream lake.

Figure 5. Regions of origin for aquatic NIS established in the Great Lakes basin since the 1830s. Source: Mills *et al*. 1993; Ricciardi 2001; Grigorovich *et al*. 2003; Ricciardi 2006

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Lake/Basin of First Discovery	**Fauna**	**Flora**	
Unknown/Widespread	33	9	
Multiple	4	1	
Ontario	24	33	
Erie	16	21	
Huron	4	3	
Michigan	11	16	
Superior	3	4	
	95	**87**	**182**

Table 1. Nonindigenous species predicted to have a high-risk of introduction to the Great Lakes.
Source: Ricciardi and Rasmussen 1998; Kolar and Lodge 2002; Grigorovich *et al*. 2003; Stokstad 2003; Rixon *et al*. 2004

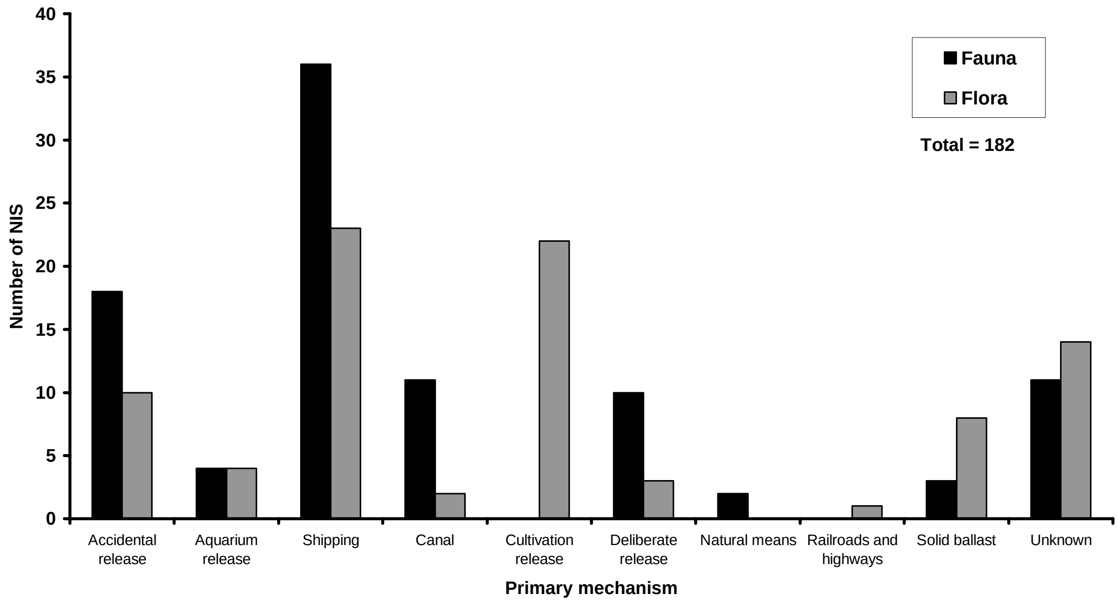

Figure 1. Release mechanisms for aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1830s.
Source: Mills *et al*. 1993; Ricciardi 2001; Grigorovich *et al*. 2003; Ricciardi 2006

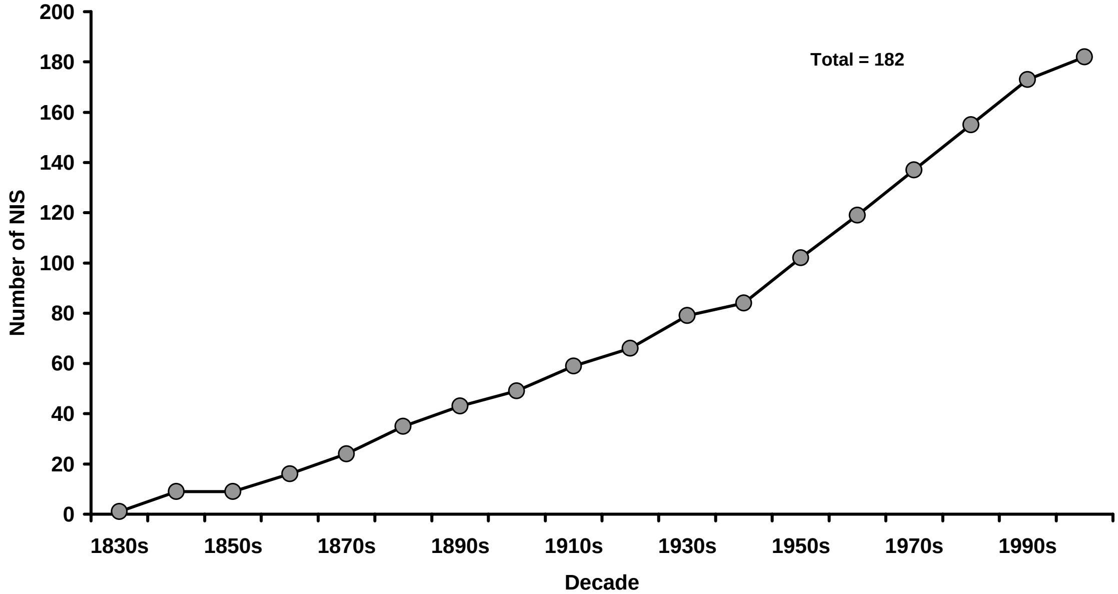

Figure 2a. Cumulative number of aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1830s attributed to all vectors.
Source: Mills *et al*. 1993; Ricciardi 2001; Grigorovich *et al*. 2003; Ricciardi 2006

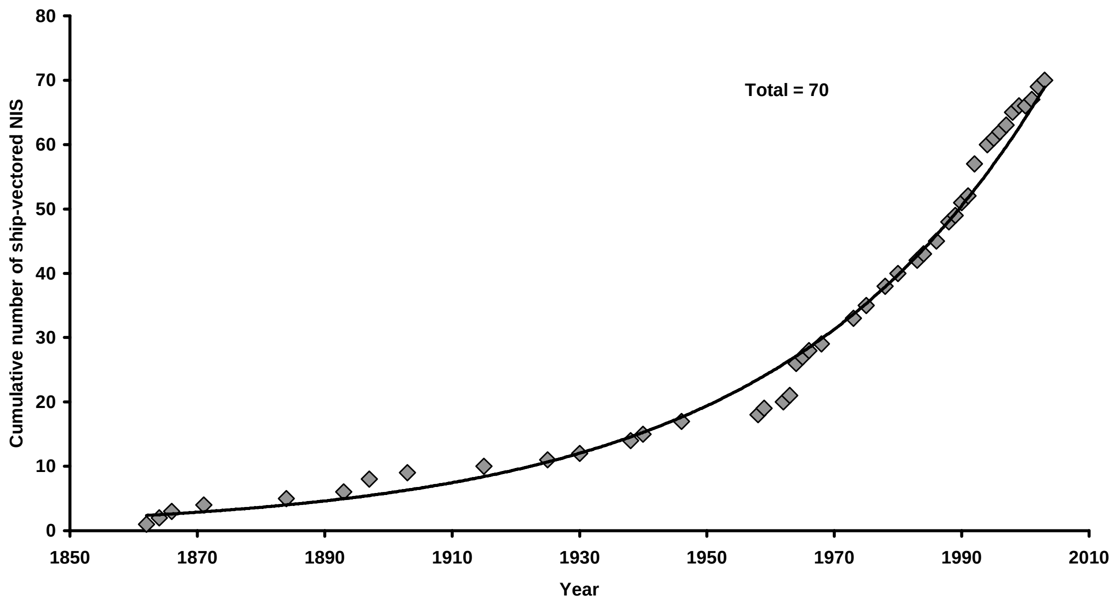

Figure 2b. Cumulative number of aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1830s attributed to the ship vector.
Source: Mills *et al*. 1993; Ricciardi 2001; Grigorovich *et al*. 2003; Ricciardi 2006

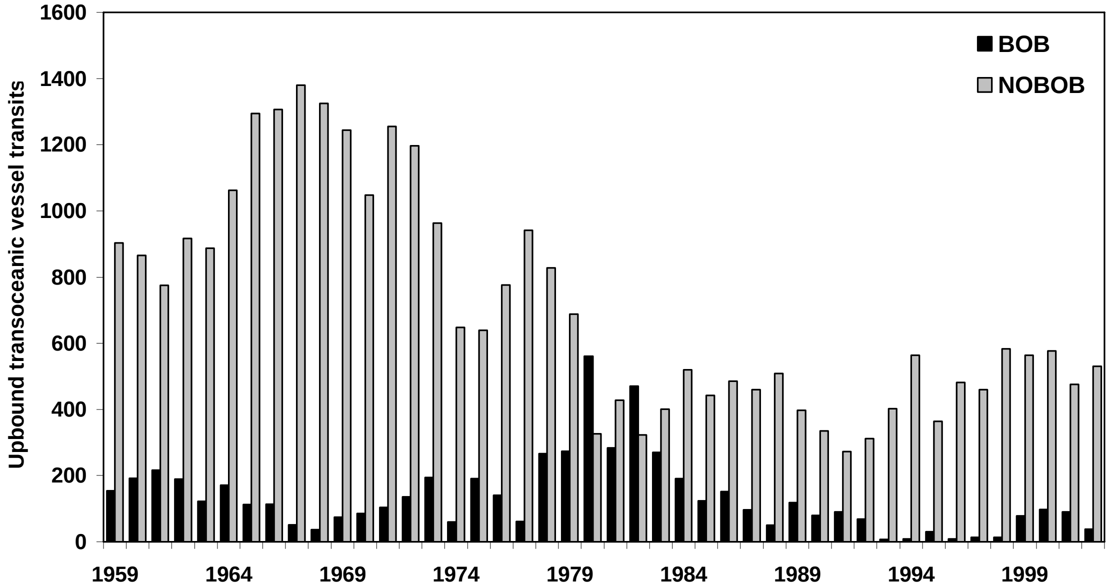

Figure 3. Numbers of upbound transoceanic vessels entering the Great Lakes from 1959 to 2002. Source: Colautti *et al*. 2003; Grigorovich *et al*. 2003; Holeck *et al*. 2004

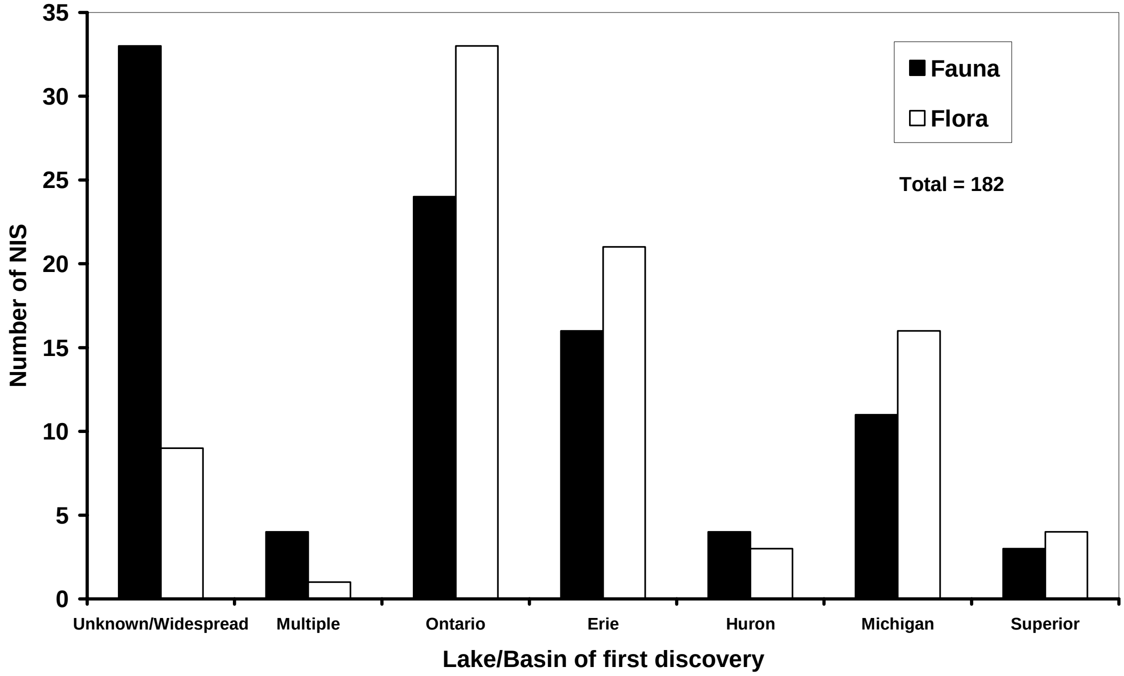

Figure 4. Lake of first discovery for NIS established in the Great Lakes basin since the 1830s. Discoveries in connecting waters between Lakes Huron, Erie and Ontario were assigned to the downstream lake.
Source: Grigorovich *et al*. 2003

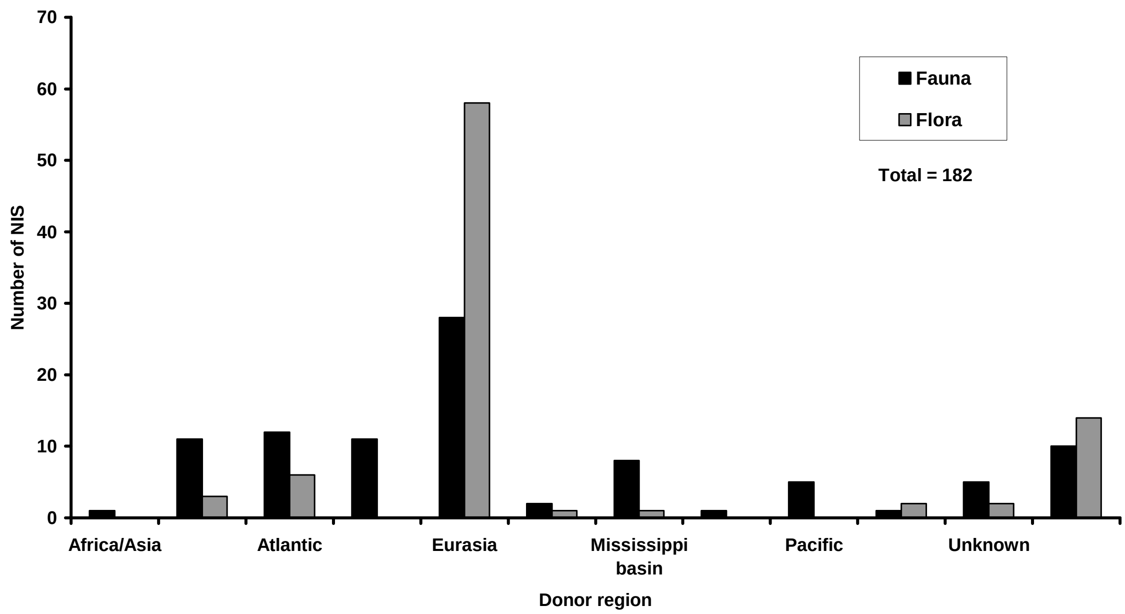

Figure 5. Regions of origin for aquatic NIS established in the Great Lakes basin since the 1830s. Source: Mills *et al*. 1993; Ricciardi 2001; Grigorovich *et al*. 2003; Ricciardi 2006

Non-native Species - Terrestrial
Indicator #9002

Overall Assessment

Status:	**Mixed**
Trend:	**Deteriorating/Undetermined**
Primary Factors Determining Status and Trend	**Terrestrial Non-indigenous species are pervasive in the Great Lakes basin. Although not all introductions have an adverse effect on native habitats, those that do pose a considerable ecological, social, and economic burden. Historically, the Great Lakes Basin has proven to be particularly vulnerable to non-indigenous species, mainly due to the high volume of transboundary movement of goods and people, population, and industrialization. Improved monitoring of non-indigenous species is needed to adequately assess the status, trends, and impacts of non-indigenous species in the region.**

Lake-by-Lake Assessment

Lake Superior

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Michigan

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Huron

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Erie

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Ontario

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Purpose

- To evaluate the presence, number, and impact of terrestrial non-indigenous species in the Great Lakes Basin.
- To assess the biological integrity of the Great Lakes Basin ecosystems.

Ecosystem Objective

The ultimate goal of this indicator is to limit, or prevent, the unauthorized introduction of non-indigenous species, and to minimize their adverse affect in the Great Lakes Basin. Such actions would assist in accomplishing one of the major objectives of U.S. and Canada Great Lakes Water Quality Agreement, which is to restore and maintain the biological integrity of the waters of the Great Lakes ecosystem.

State of the Ecosystem

Globalization, i.e. the movement of people and goods, has led to a dramatic increase in the number of terrestrial non-indigenous species (NIS) that are transported from one country to another. As a result of its high population density and high-volume transportation of goods, the Great Lakes Basin (GLB) is very susceptible to the introduction of such invaders. Figure 1 depicts this steady increase in the number of terrestrial NIS introduced into the GLB and the rate at which this has occurred, beginning in the 1900s. In addition, the degradation, fragmentation, and loss of native ecosystems have also made this region more vulnerable to these invaders, enabling them to become invasive (non-indigenous species or strains that become established in native communities or wild areas and replace native species). As such, the introduction of NIS is considered to be one of the greatest threats to the biodiversity and natural resources of this region, second only to habitat destruction.

Monitoring of NIS is largely locally based, as a region-wide standard has yet to be established. As a result, the data that is generated comes from a variety of agencies and organizations throughout the region, thus providing some difficulty when attempting to assess the overall presence and impact these species are having on the region. Information provided by the World Wildlife Fund of Canada indicates that there are 157 exotic plants and animals located within the GLB, which includes: 95 vascular plants, 11 insects, 6 plant diseases, 4 mammals, 2 birds, 2 animal diseases, 1 reptile, and 1 amphibian. However, the Invasive Plant Association of Wisconsin has identifies 116 non-native plants within the state, while over one hundred plants have been introduced into the Chicago region (Chicago Botanic Garden). Even though these figures are greater then the one provided by the WWF of Canada, they do not compare to the over 900 non-native plants that have been identified within the state of Michigan by the Michigan Invasive Plant Council.

The impact NIS have on the areas in which they are introduced can vary greatly, ranging from little or no affect to dramatically altering the native ecological community. Figure 2 shows the degree to which each taxonomic group has had an impact on the ecoregion. The WWF of Canada has listed 29 species, 19 of which are vascular plants, as having a "severe impact" on native biodiversity. These species, which were generally introduced for medicinal or ornamental purposes, have become problematic as they continue to thrive due to the fact that they are well adapted to a broad range of habitats, have no native predators, and are often able to reproduce at a rapid rate. Common buckthorn, garlic mustard, honeysuckle, purple loosestrife, and reed canary grass are several examples of highly invasive plant species, while the Asian longhorn beetle, Dutch elm disease, emerald ash borer, leafy spurge, and the West Nile virus are other terrestrial invaders that have had a significant impact of the GLB.

One type of terrestrial non-native species not covered in this report is genetically modified organisms (GMOs). Although GMOs are typically cultivated for human uses and benefits, the problem arises when pollen is moved from its intended site (often by wind or pollinator species) and transfers genetically engineered traits, such as herbicide resistance and pest resistance, to wild plants. This outward gene flow into natural habitats has the potential to significantly alter ecosystems and create scenarios that would pose enormous dilemmas for farmers. Both Canada and the U.S. are major producers of genetically modified organisms (GMOs). Although GMO crops are monitored for outward gene flow, no centralized database describing the number of GMO species, or land area covered by GMOs in the Great Lakes Basin currently exists.

There are currently numerous policies, laws and regulations within the GLB that address NIS; however, similar to NIS monitoring, they originate from state, provincial and federal administrations and thus have similar obstacles associated with them. As such, strict enforcement of these laws, in addition to continuous region-wide mitigation, eradication and management of NIS is needed in order to maintain the ecological integrity of the GLB.

Pressures

The growing transboundary movement of goods and people has heightened the need to prevent and manage terrestrial NIS. Most cases of invasiveness can be linked to the intended or unintended consequences of economic activities (Perrings, et al., 2002). For this reason, the GLB has been, and will continue to be, a hot bed of introductions, unless preventive measures are enforced. The growth in population, threats, recreation and tourism all contribute to the number of NIS affecting the region. Additionally, factors such as the increase in development and human activity, previous introductions and climate change have elevated the levels of vulnerability. Because this issue has social, ecological, and economic dimensions it can be assumed that the pressure of NIS will persist unless it is addressed on all three fronts.

Management Implications

Since the early 1800s, biological invasions have compromised the ecological integrity of the GLB. Despite an elevated awareness of the issue and efforts to prevent and manage NIS in the Great Lakes, the area remains highly vulnerable to both intentional and non-intentional introductions. Political and social motivation to address this issue is driven not only by the effects on the structure and function of regional ecosystems, but also by the cumulative economic impact of invaders, i.e. threats to food supplies and human health.

Managers of terrestrial NIS in the GLB recognize that successful management strategies must involve collaboration across federal, provincial and state governments, in addition to non-governmental organizations. Furthermore, improved integration, coordination and development of inventories, mapping, and mitigation of terrestrial invasive species can be used to adapt future strategies and examine trends in terrestrial NIS at a basin-wide scale. Although current monitoring programs in Canada are fragmented at best, a number of initiatives involving broad-stakeholder participation and government collaboration are being developed to determine future priorities. This information will be applied to risk analysis, predictive science, modeling, improved technology for prevention and management of NIS, legislation and regulations, education and outreach, and international co-operation to encompass the multi-faceted aspect of this ecological, social, and economic issue.

Comments from the author(s)

Currently, there is no central monitoring site for terrestrial NIS in Canada. In 1997 the Canadian Botanical Conservation Network put together a database on invasive plant species for Canada, but the information has not since been updated. In 2000 the World Wildlife Fund of Canada amassed information about 150 known NIS in Canada in a centralized database, based on books, journal articles, websites, and consultation with experts. The author of the chapter acknowledges that a lack of centralized data was a limitation of the project. The information contained in this indicator is based on the WWF-C database and has been updated with several more recent insect invaders present in the GLB.

Acknowledgments

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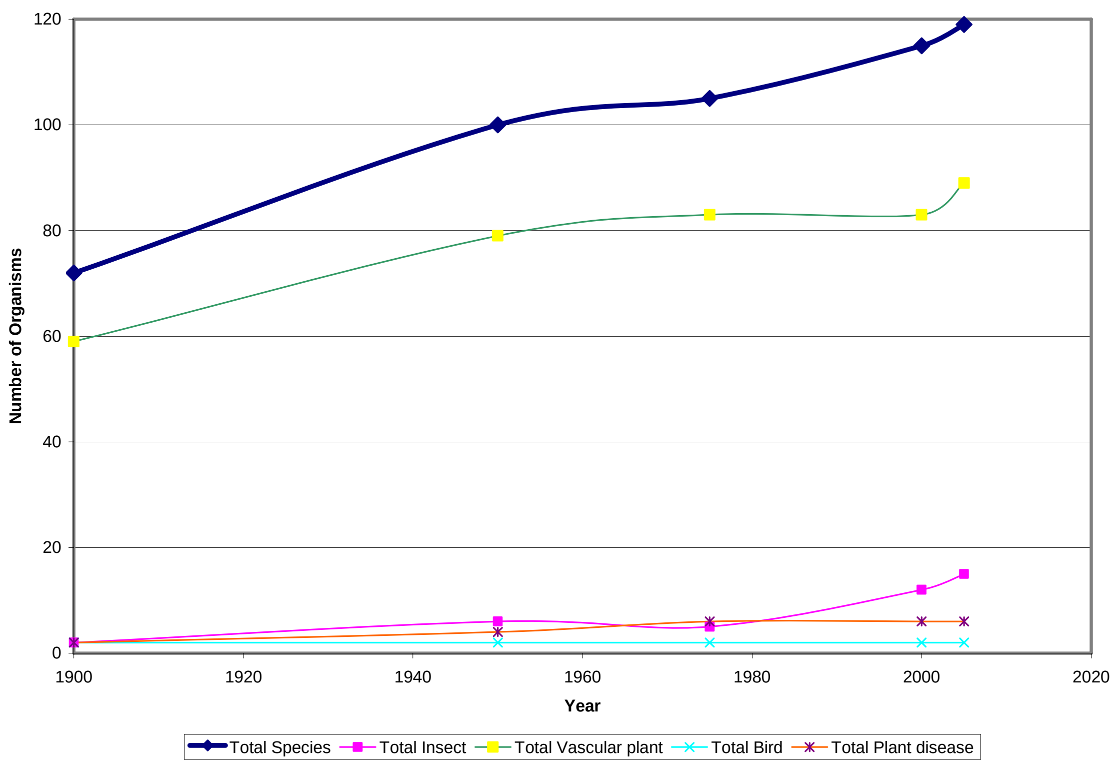

Figure 1. A timeline of terrestrial introduction in the Great Lakes Basin by taxonomic group. Data source: World Wildlife Fund-Canada's Exotic Species Database, and the Canadian Food Inspection Agency.

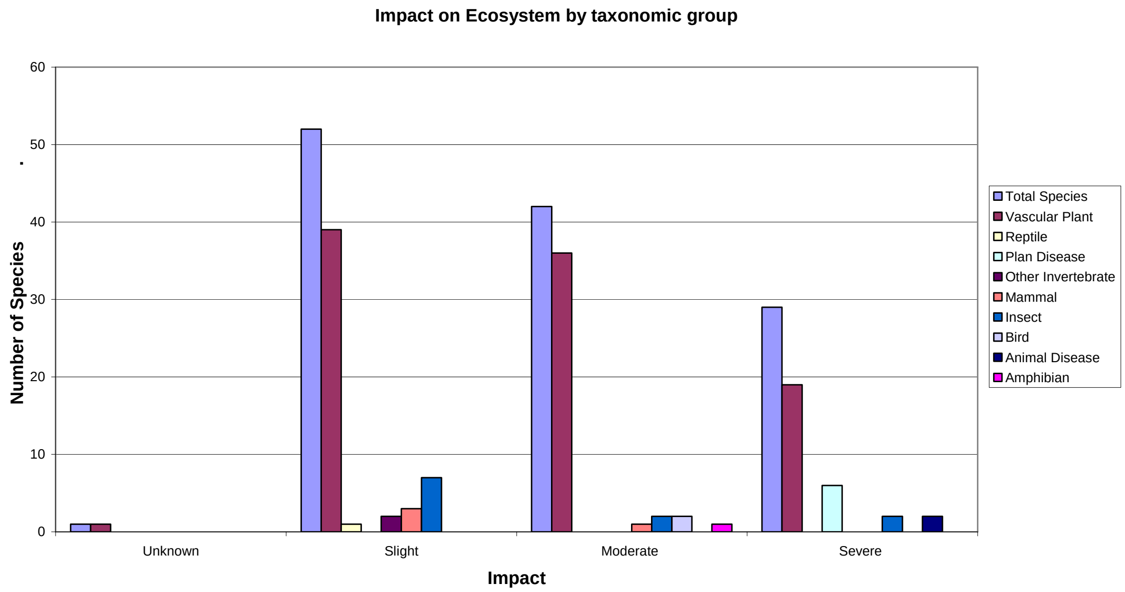

Figure 2. Estimated impact of 124 known terrestrial NIS in the Great Lakes Basin by taxonomic group.
Data source: World Wildlife Fund-Canada's Exotic Species Database.

List of indicators by category

Contamination indicators

Status, Trend	Indicator Title (indicator number)	Year
Open Lake: Mixed, Undetermined Nearshore: Poor, Undetermined	Phosphorus Concentrations and Loadings (111)	2006
Mixed, Improving SU, HU, ER, ON: mixed, improving MI: NA	Contaminants in Young-of-the-Year Spottail Shiners (114)	2006
Mixed, Improving SU: good, improving MI, HU, ER: mixed, improving ON: poor, improving	Contaminants in Colonial Nesting Waterbirds (115)	2006
Mixed, Improving/Unchanging	Atmospheric Deposition of Toxic Chemicals (117)	2006
Mixed, Undetermined SU, MI, HU: fair, undetermined ER, ON: mixed, undetermined	Toxic Chemical Concentrations in Offshore Waters (118)	2006
Mixed, Improving/Undetermined	Concentrations of Contaminants in Sediment Cores (119)	2006
Mixed, Improving SU, MI, HU, ER, ON: fair, improving	Contaminants in Whole Fish (121)	2006
Poor, Unchanging SU, MI, HU: undetermined ER, ON: poor, unchanging	External Anomaly Prevalence Index for Nearshore Fish (124)	2006
Good, Unchanging	Drinking Water Quality (4175)	2006
Mixed, Undetermined	Biologic Markers of Human Exposure to Persistent Chemicals (4177)	2006
Mixed, Improving	Contaminants in Sport Fish (4201)	2006
Mixed, Improving	Air Quality (4202)	2006
Mixed, Undetermined SU, MI, HU: undetermined ER, ON: mixed, undetermined	Contaminants in Snapping Turtle Eggs (4506)	2006
Undetermined	Nutrient Management Plans (7061)	2005
Progress Report	Wastewater Treatment and Pollution (7065)	2006
Mixed, Improving	Contaminants Affecting Productivity of Bald Eagles (8135)	2005
Mixed, Undetermined	Population Monitoring and Contaminants Affecting the American Otter (8147)	2003
Mixed, Improving	Acid Rain (9000)	2005

Biotic Communities indicators

Status, Trend	Indicator Title (indicator number)	Year
Mixed, Improving SU: fair, improving MI: mixed, slightly improving HU: fair, improving ER: good, improving ON: mixed, unchanging	Salmon and Trout (8)	**2006**
Fair, Unchanging	Walleye (9)	**2006**
Mixed, Deteriorating SU: mixed, improving MI, HU, ER, ON: mixed, deteriorating	Preyfish Populations (17)	**2006**
Undetermined	Native Freshwater Mussels (68)	**2005**
Mixed, Unchanging SU: good, improving MI: poor, declining HU: mixed, improving ER: mixed, unchanging ON: mixed, declining	Lake Trout (93)	**2006**
Mixed, Unchanging/Deteriorating SU: good, unchanging MI, ER: mixed, unchanging/deteriorating HU, ON: mixed, unchanging	Benthos Diversity and Abundance - **Aquatic Oligochaete Communities** (104)	**2006**
Mixed, Undetermined	Phytoplankton Populations (109)	**2003**
Mixed, Improving SU: good, improving MI, HU, ER: mixed, improving ON: poor, improving	Contaminants in Colonial Nesting Waterbirds (115)	**2006**
Mixed, Undetermined SU: good, unchanging MI, HU, ER, ON: undetermined	Zooplankton Populations (116)	**2006**
Mixed, Improving SU, MI, HU: poor, undetermined ER: good/mixed, improving/mixed ON: undetermined	*Hexagenia* (122)	**2006**
Mixed, Deteriorating SU: mixed, unchanging MI, HU, ER, ON: poor, deteriorating	Abundances of the Benthic Amphipod *Diporeia* spp. (123)	**2006**
Mixed, Improving SU, MI, HU: mixed, improving/undetermined ER: poor, undetermined ON: mixed, improving	Status of Lake Sturgeon in the Great Lakes (125)	**2006**
Progress Report	Coastal Wetland Invertebrate Community Health (4501)	**2005**
Undetermined	Coastal Wetland Fish Community Health (4502)	**2006**
Mixed, Deteriorating SU: undetermined MI: poor, unchanging HU, ER: mixed, deteriorating ON: mixed, unchanging	Wetland-Dependent Amphibian Diversity and Abundance (4504)	**2006**

Biotic Communities indicators (continued)

Mixed, Deteriorating SU: undetermined MI, ER, ON: mixed, deteriorating HU: poor, deteriorating	Wetland-Dependent Bird Diversity and Abundance (4507)	**2006**
Mixed, Undetermined SU: good, unchanging MI, ER: mixed, unchanging HU: mixed, deteriorating ON: poor, unchanging	Coastal Wetland Plant Community Health (4862)	**2006**
Undetermined	Groundwater Dependant Plant and Animal Communities (7103)	**2005**
Mixed, Improving	Contaminants Affecting Productivity of Bald Eagles (8135)	**2005**
Mixed, Undetermined	Population Monitoring and Contaminants Affecting the American Otter (8147)	**2003**
Mixed, Undetermined	Forest Lands-Conservation of Biological Diversity (8500)	**2006**

Invasive Species indicators

Good/Fair, Improving	Sea Lamprey (18)	**2005**
Poor, Deteriorating SU: fair, unchanging MI, HU, ER, ON: poor, deteriorating	Non-native Species—Aquatic (9002)	**2006**
Mixed, Deteriorating/Undetermined	Non-native Species—Terrestrial (9002)	**2006**

Coastal Zones indicators

Status, Trend	**Indicator Title (indicator number)**	**Year**
Progress Report	Coastal Wetland Invertebrate Community Health (4501)	2006
Undetermined	Coastal Wetland Fish Community Health (4502)	2006
Mixed, Deteriorating SU: undetermined MI: poor, unchanging HU, ER: mixed, deteriorating ON: mixed, unchanging	Wetland-dependent Amphibian Diversity and Abundance (4504)	2006
Mixed, Undetermined SU, MI, HU: undetermined ER, ON: mixed, undetermined	Contaminants in Snapping Turtle Eggs (4506)	2006
Mixed, Deteriorating SU: undetermined MI, ER, ON: mixed, deteriorating HU: poor, deteriorating	Wetland-Dependent Bird Diversity and Abundance (4507)	2006
Mixed, Deteriorating	Coastal Wetland Area by Type (4510)	2005
Mixed, Undetermined	Effect of Water Level Fluctuations (4861)	2003
Mixed, Undetermined SU: good, unchanging MI, ER: mixed, unchanging HU: mixed, deteriorating ON: poor, unchanging	Coastal Wetland Plant Community Health (4862)	2006
Progress Report	Land Cover Adjacent to Coastal Wetlands (4863)	2006
Mixed, Undetermined	Area, Quality, and Protection of Special Lakeshore Communities—Alvars (8129)	2001
Mixed, Deteriorating	Area, Quality, and Protection of Special Lakeshore Communities—Cobble beaches (8129)	2005
Progress Report	Area, Quality, and Protection of Special Lakeshore Communities—Sand dunes (8129)	2005
Mixed, Undetermined SU: good, undetermined MI: undetermined HU, ER, ON: mixed, undetermined	Area, Quality, and Protection of Special Lakeshore Communities —Islands (8129)	2006
Mixed, Deteriorating	Extent of Hardened Shoreline (8131)	2001

Aquatic Habitat indicators

Status/Trend	Indicator Title (indicator number)	Year
Open Lake: Mixed, Undetermined Nearshore: Poor, Undetermined	Phosphorus Concentrations and Loadings (111)	2006
Mixed, Improving SU, MI, HU: fair, undetermined ER, ON: mixed, undetermined	Toxic Chemical Concentrations in Offshore Waters (118)	2006
Mixed, Improving/Undetermined	Concentrations of Contaminants in Sediment Cores (119)	2006
Undetermined	Natural Groundwater Quality and Human-Induced Changes (7100)	2005
Undetermined	Groundwater and Land: Use and Intensity (7101)	2005
Mixed, Deteriorating	Base Flow Due to Groundwater Discharge (7102)	2006
Undetermined	Groundwater Dependant Plant and Animal Communities (7103)	2005
Mixed, Deteriorating	Extent of Hardened Shoreline (8131)	2001

Other sources of aquatic habitat information

Additional information on spatial and temporal trends in toxic contaminants in offshore waters can be found in:

Marvin, C., S. Painter, D. Williams, V. Richardson, R. Rossmann, and P.Van Hoof. 2004. Spatial and temporal trends in surface water and sediment contamination in the Laurentian Great Lakes. Environmental Pollution. 129(2004): 131-144.

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Great Lakes Binational Toxics Strategy Assessment of Level 1 Substances Summary. Great Lakes Binational Toxics Strategy (December 2005). U.S. EPA, Great Lakes National Program Office and Environment Canada.

Additional information on base flow can be found in:

Neff, B.P., Day, S.M., Piggot, A.R., Fuller, L.M. 2005. Base Flow in the Great Lakes Basin: U.S. Geological Survey Scientific Investigations Report 2005-5217, 23p.

Resource Utilization indicators

Status/trend	Indicator Title (indicator number)	Year
Undetermined	Commercial/Industrial Eco-Efficiency Measures (3514)	2003
Mixed, Undetermined SU: Mixed, Undetermined MI, HU, ER, ON: undetermined	Economic Prosperity (7043)	2003
Mixed, Unchanging	Water Withdrawals (7056)	2005
Mixed, Undetermined	Energy Consumption (7057)	2005
Undetermined	Solid Waste Disposal (7060)	2006
Poor, Deteriorating	Vehicle Use (7064)	2006
Progress Report	Wastewater Treatment and Pollution (7065)	2006

Land Use – Land Cover indicators

Status/Trend	Indicator Title (indicator number)	Year
Progress Report	Land Cover Adjacent to Coastal Wetlands (4863)	2006
Mixed, Undetermined	Urban Density (7000)	2006
Undetermined	Groundwater and Land: Use and Intensity (7101)	2005
Mixed, Undetermined	Land Cover/Land Conversion (7002)	2006
Mixed, Improving	Brownfields Redevelopment (7006)	2006
Undetermined	Sustainable Agricultural Practices (7028)	2005
Progress Report	Ground Surface Hardening (7054)	2005
Undetermined	Nutrient Management Plans (7061)	2005
Undetermined	Integrated Pest Management (7062)	2005
Mixed, Undetermined	Area, Quality and Protection of Special Lakeshore Communities – Alvars (8129)	2001
Mixed, Deteriorating	Area, Quality and Protection of Special Lakeshore Communities – Cobble Beaches (8129)	2005
Mixed, Undetermined SU: good, undetermined MI: undetermined HU, ER, ON: mixed, undetermined	Area, Quality and Protection of Special Lakeshore Communities – Islands (8129)	2006
Progress Report	Area, Quality and Protection of Special Lakeshore Communities – Sand Dunes (8129)	2005
Undetermined (Proposed Indicator)	Biodiversity Conservation Sites (8164)	2006
Mixed, Undetermined	Forest Lands – Conservation of Biological Diversity (8500)	2006
Undetermined	Forest Lands – Maintenance of Productive Capacity of Forest Ecosystems (8501)	2006
Mixed, Undetermined	Forest Lands – Conservation and Maintenance of Soil and Water Resources (8503)	2006

Human Health indicators

Status-Trend	Indicator Title (indicator number)	Year
Good, Unchanging	Drinking Water Quality (4175)	2006
Mixed, Undetermined	Biological Markers of Human Exposure to Persistent Chemicals (4177)	2006
Mixed, Unchanging SU: good, undertermined MI, ER, ON: fair, undetermined HU: good, unchanging/undetermined	Beach Advisories, Postings and Closures (4200)	2006
Mixed, Improving	Contaminants in Sport Fish (4201)	2006
Mixed, Improving	Air Quality (4202)	2006

Other sources of human health information:
Lake Wide Management Plans http://www.epa.gov/glnpo/gl2000/lamps/index.html
Agency for Toxic Substances and Disease Registry http://www.atsdr.cdc.gov/grtlakes/index.html

Climate Change indicators

Mixed, Deteriorating	Climate Change: Ice Duration on the Great Lakes (4858)	2003

Other sources of climate change information:
http://www.usgcrp.gov/usgcrp/nacc/greatlakes.htm
http://www.nrel.colostate.edu/projects/brd_global_change/proj_31_great_lakes.html
http://www.geo.msu.edu/glra/assessment/assessment.html
http://www.glerl.noaa.gov/res/Programs/ccmain.html
http://www.ucsusa.org/greatlakes/

6.0 Acronyms and Abbreviations

Agencies and Organizations

ATSDR	Agency for Toxic Substances and Disease Registry
CAMNet	Canadian Atmospheric Mercury Network
CCME	Canadian Council of Ministers of the Environment
CDC	Center for Disease Control (U.S.)
CIS	Canada Ice Service
CORA	Chippewa Ottawa Resource Authority
CWS	Canadian Wildlife Service
DFO	Canada Department of Fisheries and Oceans
EC	Environment Canada
ECO	Environmental Careers Organization
EIA	Energy Information Administration (U.S.)
GLBET	Great Lakes Basin Ecosystem Team (USFWS)
GLC	Great Lakes Commission
GLCWC	Great Lakes Coastal Wetlands Consortium
GLFC	Great Lakes Fishery Commission
GLNPO	Great Lakes National Program Office (USEPA)
IJC	International Joint Commission
IUCN	International Union for the Conservation of Nature
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
NHEERL	National Health & Environmental Effects Research Laboratory (USEPA)
NOAA	National Oceanic and Atmospheric Administration
NRC	Natural Resources Canada
NRCS	Natural Resources Conservation Service (USDA)
NYSDEC	New York State Department of Environmental Conservation
ODNR	Ohio Department of Natural Resources
ODW	Ohio Division of Wildlife
OFEC	Ontario Farm Environmental Coalition
OMAF	Ontario Ministry of Agriculture and Food
OMOE	Ontario Ministry of Environment
OMNR	Ontario Ministry of Natural Resources
OSCIA	Ontario Soil and Crop Improvement Association
ORISE	Oak Ridge Institute for Science and Education
PDEP	Pennsylvania Department of Environmental Protection
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFDA	U.S. Food and Drug Administration
USFWS	U.S. Fish and Wildlife Service
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WBCSD	World Business Council for Sustainable Development
WDNR	Wisconsin Department of Natural Resources
WDO	Waste Diversion Organization (Ontario)
WiDPH	Wisconsin Department of Public Health

Units of Measure

fg	femptogram, 10^{-15} gram
ha	hectare, 10,000 square metres, 2.47 acres
kg	kilogram, 1000 grams, 2.2 pounds
km	kilometre, 0.62 miles
kt	kiloton
kWh	kilowat-hour
m	metre

mg	milligram, 10^{-3} gram
mg/kg	milligram per kilogram, part per million
mg/l	milligram per litre
ml	milliliter, 10^{-3} litre
MWh	megawatt-hour
ng	nanogram, 10^{-9} gram
ng/g	nanogram per gram, part per billion
pg	picogram, 10^{-12} gram
ppb	part per billion
ppm	part per million
ton	English ton, 2000 lb
tonne	metric tonne: 1000 kg, 2200 lb
µg	microgram, 10^{-6} gram
µg/g	microgram per gram, part per million
$\mu g/m^3$	microgram per cubic metre
µm	micrometer, micron, 10^{-6} metre

<u>Chemicals</u>

2,4-D	2,4-dichlorophenoxyacetic acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
BaP	Benzo[α]pyrene
BFR	Brominated flame retardants
CO	Carbon monoxide
DDT	1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane or dichlorodiphenyl-trichloroethane
DDD	1,1-dichloro-2,2-bis(p-chlorophenyl) ethane
DDE	1,1-dichloro-2,2-bis(chlorophenyl) ethylene or dichlorodiphenyl-dichloroethene
DOC	Dissolved organic carbon
HBCD	Hexabromocyclododecane
HCB	Hexachlorobenzene
α-HCH	Hexachlorocyclohexane
γ-HCH	Lindane
HE	Heptachlor epoxide
MeHg	Methylmercury
NAPH	Naphthalene
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NTU	Nephelometric turbidity unit
PAH	Polynuclear aromatic hydrocarbons
PBDE	Polybrominated diphenyl ether
PCA	Polychlorinated alkanes
PCB	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-*p*-dioxin
PCDF	Polychlorinated dibenzo furan
PCN	Polychlorinated naphthalenes
PFOA	Perfluorooctanoic acid
PFOS	Perfluoroctanyl sulfonate
PM_{10}	Atmospheric particulate matter of diameter 10 microns or smaller
$PM_{2.5}$	Atmospheric particulate matter of diameter 2.5 microns or smaller
SO_2	Sulfur dioxide
SPCB	Suite of PCB congeners that include most of PCB mass in the environment
TCDD	Tetrachlorodibenzo-*p*-dioxin
TCE	Trichloroethylene
TDS	Total dissolved solids
TOC	Total organic carbon
TRS	Total reduced sulfur
VOC	Volatile organic compound

Other

AAQC	Ambient Air Quality Criterion (Ontario)
AFO	Animal Feeding Operation
AOC	Area of Concern
APF	Agricultural Policy Framework (Canada)
ARET	Accelerated Reduction/Elimination of Toxics program (Canada)
BEACH	Beaches Environmental Assessment and Coastal Health (U.S. Act of 2000)
BKD	Bacterial Kidney Disease
BMP	Best Management Practices
BOB	Ballast On Board
BOD	Biochemical Oxygen Demand
CAFO	Concentrated Animal Feeding Operations
C-CAP	Coastal Change and Analysis Program (land cover)
CC/WQR	Consumer Confidence/Water Quality Report (drinking water)
CFU	Colony Forming Units
CHT	Contaminants in Human Tissue program (part of EAGLE)
CMA	Census Metropolitan Area
CNMP	Comprehensive Nutrient Management Plan (U.S.)
CSO	Combined Sewer Overflow
CUE	Catch per Unit of Effort
CWS	Canada-wide Standard (air quality)
DWS	Drinking Water System (Canada)
EAGLE	Effects on Aboriginals of the Great Lakes program
DWSP	Drinking Water Surveillance Program (Canada)
EAPI	External Anomaly Prevalence Index
EFP	Environmental Farm Plan (Ontario)
EMS	Early Mortality Syndrome
FCO	Fish Community Objectives
FIA	Forest Inventory and Analysis (USDA Forest Service)
FQI	Floristic Quality Index
GAP	Gap Analysis Program (land cover assessment)
GIS	Geographic Information System
GLWQA	Great Lakes Water Quality Agreement
HUC	Hydrologic Unit Code
IACI	International Alvar Conservation Initiative
IADN	Integrated Atmospheric Deposition Network
IBI	Index of Biotic Integrity
IGLD	International Great Lakes Datum (water level)
IMAC	Interim Maximum Acceptable Concentration
IPM	Integrated Pest Management
ISA	Impervious Surface Area
LaMP	Lakewide Management Plan
LEL	Lowest Effect Level
MAC	Maximum Acceptable Concentration
MACT	Maximum Available Control Technology
MCL	Maximum Contaminant Level
MGD	Million Gallons per Day (3785.4 m^3 per day)
MMP	Marsh Monitoring Program
MSA	Metropolitan Statistical Area
MSWG	Municipal Solid Waste Generation
NAFTA	North America Free Trade Agreement
NATTS	National Air Toxics Trend Site (U.S. network)
NEI	National Emissions Inventory (U.S.)
NHANES	National Health and Nutrition Examination Survey (CDC)
NIS	Nonindigenous species

NLCD	National Land Cover Data
NMP	Nutrient Management Plan (Ontario)
NOAEC	No Observable Adverse Effect Concentrations
NOAEL	No Observable Adverse Effect Level
NOBOB	No Ballast On Board
NPDES	National Pollution Discharge Elimination System (U.S.)
NPRI	National Pollutant Release Inventory (Canada)
NRVIS	Natural Resources and Values Information System (OMNR)
ODWQS	Ontario Drinking Water Quality Standard
OPEP	Ontario Pesticides Education Program
PEL	Probable Effect Level
PBT	Persistent Bioaccumulative Toxic (chemical)
PNP	Permit Nutrient Plans (U.S.)
PGMN	Provincial Groundwater-Monitoring Network (Ontario)
RAP	Remedial Action Plan
SDWIS	Safe Drinking Water Information System (U.S.)
SOLEC	State of the Lakes Ecosystem Conference
SOLRIS	Southern Ontario Land Resource Information System
SQI	Sediment Quality Index
SSO	Sanitary Sewer Overflow
SWMRS	Seasonal Water Monitoring and Reporting System (Canada)
TCR	Total Coliform Rule
TDI	Tolerable Daily Intake
TEQ	Toxic Equivalent
TIGER	Topological Integrated Geographic Encoding and Reference (U.S. Census Bureau)
TRI	Toxics Release Inventory (U.S.)
UNECE	United Nations Economic Commission for Europe
WIC	Women Infant and Child (Wisconsin health clinics)
WISCLAND	Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data
WTP	Water Treatment Plant (U.S.)

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U.S. Geological Survey
- Biological Resources Division
- Great Lakes Science Center
  - Lake Erie Biological Station
  - Lake Ontario Biological Station
  - Lake Superior Biological Station
- Water Resources Discipline

Provincial and State
Illinois Department of Natural Resources
Illinois Environmental Protection Agency
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Coalitions
Binational Collaborative for the Conservation of Great Lakes Islands
Great Lakes Coastal Wetlands Consortium
Great Lakes Environmental Indicators

Commissions
Great Lakes Commission
Great Lakes Fishery Commission
Great Lakes Indian Fish and Wildlife Commission
International Joint Commission

Environmental Non-Government Organizations

Bird Studies Canada
Great Lakes Forest Alliance
Great Lakes United
The Nature Conservancy

Industry
American Forests and Paper Association
Council of Great Lakes Industries
National Council for Air and Stream Improvement, Inc.

Private Organizations
Bio-Software Environmental Data
Bobolink Enterprises
DynCorp, A CSC Company
Environmental Careers Organization
LURA Consulting
Oak Ridge Institute for Science and Education
Stream Benders

Private Citizens