State of the Great Lakes

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State of the Great Lakes 2005

by the Governments of
Canada
and
the United States of America

Prepared by
Environment Canada
and the
U.S. Environmental Protection Agency

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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 2005**, 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 Toronto, Ontario, October 6-8, 2004. The sources of information are acknowledged within each section.

Expanding upon previous State of the Great Lakes reporting systems, the 2005 information is presented in three different ways:

State of the Great Lakes 2005. This technical report contains the full indicator reports as prepared by the primary authors, the indicator category assessments, the lake and river assessments and management challenges. It also contains detailed references to the data sources.

State of the Great Lakes 2005 Highlights. This report highlights key information presented in the main report.

State of the Great Lakes 2005 Indicator 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 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.

1.0 Introduction

This **State of the Great Lakes 2005** report represents the compilation, scientific analysis and interpretation of data about the Great Lakes basin ecosystem, prepared by many organizations in both the United States and Canada. The information contained within these pages 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 sixth in a series of reports beginning in 1995, the **State of the Great Lakes 2005** 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 reporting requirements of the Great Lakes Water Quality Agreement (GLWQA) that call 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, based on information presented and discussed at the conference and post-conference comments, is prepared by Canada and the U.S. Additional information about SOLEC and the Great Lakes indicators is available at www.binational.net.

After the **State of the Great Lakes 2003** report was issued, two reviews of SOLEC processes and products were conducted. One was a review by experts on indicator systems outside the Great Lakes basin to evaluate the overall effectiveness and efficiency of SOLEC, and the other was a review by Great Lakes stakeholders to evaluate the entire suite of indicators developed to date. Significant improvements in both the SOLEC process and the configuration of the indicator suite were made as a result of these reviews, including the deletion, modification, addition or combination of indicators. Details of the modifications are documented in a companion report, *The Great Lakes Indicators Suite: Changes and Progress 2004*.

The **State of the Great Lakes 2005** provides an assessment of each of the five Great Lakes, the St. Clair-Detroit River ecosystem, the St. Lawrence River, assessments of 56 of approximately 80 ecosystem indicators and assessments of the indicator categories. The concept of indicator categories is new for this report with indicators grouped into one or more of the following categories: Contamination, Biotic Communities, Invasive Species, Coastal Zones, Aquatic Habitats, Human Health, Land Use-Land Cover, Resource Utilization, and Climate Change. Within most of the main categories are sub-categories to further delineate issues or geographic areas.

The assessments for each indicator and for the Lake and River reports have been modified slightly to provide both a "status" component (Good, Fair, Poor, Mixed) and a "trend" component (Improving, Unchanging, Deteriorating, Undetermined). Definitions for these rankings are as follows:

Status

- **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.

Trend

- **Improving.** Information provided by the report shows the ecosystem component(s) to be changing toward more acceptable conditions.
- **Unchanging.** Information provided by the report shows the ecosystem component(s) is/are neither getting better nor worse.
- **Deteriorating.** Information provided by the report shows the ecosystem component(s) to be changing away from acceptable conditions.
- **Undetermined.** Data are not available to assess the ecosystem component(s) over time, so no trend can be identified.

The purpose of the GLWQA is "*to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem.*" These terms were not defined in the Agreement, but through the SOLEC process, definitions and practical applications of these terms are being developed. SOLEC 2002 focussed on biological integrity while SOLEC 2006 will focus on chemical integrity. In the present report, the Lake and River assessments focus on physical integrity which was a theme at SOLEC 2004.

The conclusion of this **State of the Great Lakes 2005** report is that the status of the Great Lakes basin ecosystem is *Mixed* and *Unchanging* based on Lake, River, indicator category and 56 individual indicator assessments.

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

- Persistent toxic substances are continuing to decline.
- The Great Lakes are a good source for treated drinking water.
- Total forested land in the Great Lakes basin appears to have increased in recent decades. Approximately 50% of the Great Lakes basin is covered by forest.
- Bald eagles are continuing to nest and fledge along the Great Lakes shorelines.
- Lake trout stocks in Lake Superior have remained self-sustaining.
- Natural reproduction of lake trout is evident in Lake Ontario and in isolated areas of Lake Huron.
- Mayfly (*Hexagenia*) populations have partially recovered in western Lake Erie and in the Bay of Quinte, Lake Ontario.
- Phosphorus targets have been met in Lakes Ontario, Huron, Michigan and Superior.

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

- Non-native species are a significant threat to the ecosystem and continue to enter the Great Lakes (aquatic and terrestrial species).
- Scud (*Diporeia*) populations continue to decline in Lakes Michigan, Ontario and Huron.
- Type E Botulism outbreaks, resulting in the deaths of fish and fish-eating birds, have recently been detected in a few locations along the Lake Ontario shoreline, and minor outbreaks are continuing in Lake Erie.
- Groundwater resources are being negatively impacted by development, withdrawal and agricultural drainage.
- Long range atmospheric transport is a continuing source of contaminants to the Great Lakes basin.
- Native mussel populations continue to be decimated as a result of invasive zebra mussels.
- 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.
- Phosphorus levels are still above guidelines in Lake Erie.

In addition to these known negative features, certain compounds such as brominated flame retardants, personal care products, and pharmaceuticals are raising concerns as to their potential impacts on the biota in the Great Lakes ecosystem.

The **State of the Great Lakes 2005** report is a comprehensive overview of ecosystem conditions in the Great Lakes basin. The three sections that follow provide the latest information pulled together by experts from the Great Lakes community. Section 2.0 offers a discussion of management challenges resulting from discussions held at SOLEC 2004 and from the indicator reports. Section 3.0 contains the Lake and River assessments. Section 4.0 begins with the indicator category assessments which are followed by a report for each of the 56 indicators.

The listing of the **State of the Great Lakes 2005** indicator reports, the categories, and the indicator assessments for 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 5.0.

ID #	Indicator Name	2005 Assessment (Status, Trend)	2003 Assessment	2001 Assessment
CONTAMINATION Category				
Nutrients				
111	Phosphorus Concentrations and Loadings	Mixed, Undetermined	Mixed	Mixed
7061	Nutrient Management Plans	N/A	N/A	
Toxics in Biota				
114	Contaminants in Young-of-the-Year Spottail Shiners	Mixed, Improving	Mixed Improving	
115	Contaminants in Colonial Nesting Waterbirds	Mixed, Improving	Mixed Improving	Good
121	Contaminants in Whole Fish	Mixed, Improving	N/A	
124	External Anomaly Prevalence Index for Nearshore Fish	Poor-Mixed, Undetermined	N/A (#101)	
4177	Biologic Markers of Human Exposure to Persistent Chemicals	Mixed, Undetermined		
4201	Contaminants in Sport Fish	Mixed, Improving	Mixed Improving (#4083)	Mixed Improving (#4083)
4506	Contaminants in Snapping Turtle Eggs	Mixed, N/A	Mixed	Mixed
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, Improving	Mixed Improving	Mixed Improving
8147	Population Monitoring and Contaminants Affecting the American Otter	(2003 report)	Mixed	N/A
Toxics in Media				
117	Atmospheric Deposition of Toxic Chemicals	Mixed, Improving & Mixed, Unchanging	Mixed	Mixed Improving
118	Toxic Chemical Concentrations in Offshore Waters	Mixed, Improving	Mixed Improving	Mixed
119	Concentrations of Contaminants in Sediment Cores	Mixed, Improving	Mixed Improving	
4175	Drinking Water Quality	Good, Unchanging	Good	Good
4202	Air Quality	Mixed, Improving	Mixed (#4176)	Mixed (#4176)
9000	Acid Rain	Mixed, Improving	Mixed Improving	Mixed
Sources and Loadings				
117	Atmospheric Deposition of Toxic Chemicals	Mixed, Improving & Mixed, Unchanging	Mixed	Mixed Improving
4202	Air Quality	Mixed, Improving	Mixed (#4176)	Mixed (#4176)
9000	Acid Rain	Mixed, Improving	Mixed Improving	Mixed
BIOTIC COMMUNITIES				
Fish				
8	Salmon and Trout	Mixed, Improving	Mixed	
9	Walleye	Good, Unchanging	Mixed	Good
17	Preyfish Populations	Mixed, Deteriorating Mixed, Improving	Mixed Deteriorating	Mixed Improving
93	Lake Trout	Mixed, Improving & Mixed, Unchanging	Mixed	Mixed
125	Status of Lake Sturgeon in the Great Lakes	Mixed, Undetermined	N/A	
4502	Coastal Wetland Fish Community Health	N/A		
Birds				
115	Contaminants in Colonial Nesting Waterbirds	Mixed, Improving	Mixed Improving	Good

N/A = Not Assessed, Number in bracket indicates related indicator

ID #	Indicator Name	2005 Assessment (Status, Trend)	2003 Assessment	2001 Assessment
BIOTIC COMMUNITIES (CONTINUED)				
4507	Wetland-Dependent Bird Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, Improving	Mixed Improving	Mixed Improving
Mammals				
8147	Population Monitoring and Contaminants Affecting the American Otter	(2003 report)	Mixed	N/A
Amphibians				
4504	Coastal Wetland Amphibian Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
7103	Groundwater Dependant Plant and Animal Communities	N/A		
Invertebrates				
68	Native Freshwater Mussels	N/A	N/A	Mixed Deteriorating
104	Benthos Diversity and Abundance - Aquatic Oligochaete Communities	(2003 report)	Mixed	
116	Zooplankon Populations	(2003 report)	N/A	Mixed
122	*Hexagenia*	Mixed, Improving	Mixed Improving	Mixed Improving
123	Abundances of the Benthic Amphipod *Diporeia* spp.	Mixed, Deteriorating	Mixed Deteriorating	Mixed
4501	Coastal Wetland Invertebrate Community Health	N/A		
Plants				
109	Phytoplankton Populations	(2003 report)	Mixed	Mixed
4862	Coastal Wetland Plant Community Health	Mixed, Undetermined		
8500	Forest Lands - Conservation of Biological Diversity	Mixed, Improving		
INVASIVE SPECIES				
Aquatic				
18	Sea Lamprey	Good-Fair, Improving	Mixed Improving	Mixed
9002	Non-Native Species (Aquatic)	Poor, Deteriorating	Poor	Poor
COASTAL ZONES				
Nearshore Aquatic				
4861	Effect of Water Levels Fluctuations	(2003 report)	Mixed	Mixed Deteriorating
8131	Extent of Hardened Shoreline	(2001 report)	(2001 report)	Mixed Deteriorating
Coastal Wetlands				
4501	Coastal Wetland Invertebrate Community Health	N/A		
4502	Coastal Wetland Fish Community Health	N/A		
4504	Coastal Wetland Amphibian Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
4506	Contaminants in Snapping Turtle Eggs	Mixed, N/A	Mixed	Mixed
4507	Wetland-Dependent Bird Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
4510	Coastal Wetland Area by Type	Mixed, Deteriorating	(2001 report)	Mixed Deteriorating

N/A = Not Assessed, Number in bracket indicates related indicator

ID #	Indicator Name	2005 Assessment (Status, Trend)	2003 Assessment	2001 Assessment
COASTAL ZONES (CONTINUED)				
4861	Effects of Water Levels Fluctuations	(2003 report)	Mixed	Mixed Deteriorating
4862	Coastal Wetland Plant Community Health	Mixed, Undetermined		
Terrestrial				
4861	Effects of Water Levels Fluctuations	(2003 report)	Mixed	Mixed Deteriorating
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	(2001 report)	(2001 report)	Mixed
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	Mixed, Deteriorating		
8131	Extent of Hardened Shoreline	(2001 report)	(2001 report)	Mixed Deteriorating
AQUATIC HABITATS				
Open Lake				
111	Phosphorus Concentrations and Loadings	Mixed, Undetermined	Mixed	Mixed
118	Toxic Chemical Concentrations in Offshore Waters	Mixed, Improving	Mixed Improving	Mixed
119	Concentrations of Contaminants in Sediment Cores	Mixed, Improving	Mixed Improving	
8131	Extent of Hardened Shoreline	(2001 report)	(2001 report)	Mixed Deteriorating
Groundwater				
7100	Natural Groundwater Quality and Human-Induced Changes	N/A	N/A	
7101	Groundwater and Land: Use and Intensity	N/A	N/A	
7102	Base Flow Due to Groundwater Discharge	Mixed, Deteriorating	N/A	
7103	Groundwater Dependant Plant and Animal Communities	N/A		
HUMAN HEALTH				
4175	Drinking Water Quality	Good, Unchanging	Good	Good
4177	Biologic Markers of Human Exposure to Persistent Chemicals	Mixed, Undetermined		
4200	Beach Advisories, Postings and Closures	Mixed, Undetermined	Mixed (#4081)	Mixed (#4081)
4201	Contaminants in Sport Fish	Mixed, Improving	Mixed Improving (#4083)	Mixed Improving (#4083)
4202	Air Quality	Mixed, Improving	Mixed (#4176)	Mixed (#4176)
LAND USE - LAND COVER				
General				
7002	Land Cover / Land Conversion	N/A		
7101	Groundwater and Land: Use and Intensity	N/A	N/A	
Forest Lands				
8500	Forest Lands-Conservation of Biological Diversity	Mixed, Improving		
Agricultural Lands				
7028	Sustainable Agriculture Practices	N/A	N/A	Mixed

N/A = Not Assessed, Number in bracket indicates related indicator

ID #	Indicator Name	2005 Assessment (Status, Trend)	2003 Assessment	2001 Assessment
LAND USE – LAND COVER (CONTINUED)				
7061	Nutrient Management Plans	N/A		
7062	Integrated Pest Management	N/A		
Urban/Suburban Lands				
7000	Urban Density	Mixed, N/A	Mixed Deteriorating	Unable to Assess
7006	Brownfields Redevelopment	(2003 report)	Mixed Improving	Mixed Improving
Protected Areas				
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	(2001 report)	(2001 report)	Mixed
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	Mixed, Deteriorating		
RESOURCE UTILIZATION				
3514	Commercial/Industrial Eco-Efficiency Measures	(2003 report)	N/A	
7043	Economic Prosperity	(2003 report)	Mixed (L. Superior basin)	Mixed
7056	Water Withdrawals	Mixed, Unchanging		
7057	Energy Consumption	Mixed, N/A	Mixed Deteriorating	
7060	Solid Waste Generation	(2003 report)	Mixed	
CLIMATE CHANGE				
4858	Climate Change: Ice Duration on the Great Lakes	(2003 report)	Mixed Deteriorating	

N/A = Not Assessed, Number in bracket indicates related indicator

2.0 Management Challenges

Several management challenges, highlighted below, were identified and discussed through the SOLEC process, including: a special session of Great Lakes environmental managers; comments provided by SOLEC participants; and challenges reported in the lake, river and indicator assessment reports. The management challenges focus on the protection and restoration of the Great Lakes basin, including land use, habitat degradation and loss, climate change impacts and toxic contamination. The management challenges also consider future potential impacts of chemicals of emerging concern, non-native species and the inevitable stress from an increasing human population.

Land Use
Management Challenge: What land use practices will sustain the ecosystem over the long term, thereby contributing to improvements in the quality of land and water?

Current land use practices throughout the basin are affecting the chemical, physical and biological aspects of the ecosystem including the quality of land, water, and quality of life for all biota. Land is inextricably connected to the water and land use practices in the Great Lakes basin will ultimately have an impact on the water. Each Lake and River assessment presented in this report cites the need for improved land use practices to counter the effects of urban sprawl and increased population growth. Population growth is inevitable. However, where the growth occurs can be managed (protecting groundwater recharge areas from development, for example). There is a need to demonstrate and encourage environmentally-friendly land use practices, e.g., restrict where the urban growth occurs to limit the impact on habitat, air and water quality.

Management Challenge: How can managers consider both the environment and the economy when making decisions on land use?

Management of the uses of land with the view to improving the environment can be difficult when land uses are driven by market pressures. Enlightened managers (whether private land owners and developers or public service employees), however, should seek assistance from the many planning tools and decision support systems that are currently available. In addition to federal, state and provincial agencies which may advocate and support sustainable development efforts, examples of on-line availability of information and tools include the Smart Growth Network (www.smartgrowth.org), Sustainable Communities Network (www.sustainable.org), American Planning Association (www.planning.org) and Cyburbia, The Urban Planning Portal (www.cyburbia.org). While reference to these sites should not be construed as an endorsement, they do illustrate the importance of careful planning and implementation for sustainable land use practices.

Habitat Degradation and Loss
Management Challenge: How can essential habitats be protected and restored to preserve the native species and the unique and globally significant characteristics of the Great Lakes ecosystem?

Many factors, including the spread of non-native species, urbanization and population growth, degrade and decrease the amount of available plant and animal habitats. For example: native mussel species are facing extinction due to pressures from non-native zebra and quagga mussels; hydrological alterations are impacting the functioning of wetland habitats; and, poorly planned development (as discussed in the Land Use section above) is degrading or destroying essential habitats and migration corridors. Defining and identifying essential habitats in the Great Lakes are critical along with actions promoting ecological protection and restoration in the basin. Managers need current data and research to determine appropriate ecological protection and restoration tools and technologies including the ability to identify the location, viability and amount of habitat required to sustain a particular species. Monitoring programs to document species trends in abundance and distribution and educational programs that provide the public with a broad spectrum of actions to assist with the preservation of species' habitats are also required.

Management Challenge: How do managers know when there is enough habitat in the Great Lakes basin and enough biodiversity on a unit of land?

With the current rate of habitat lost or degraded by factors such as increasing urbanization and the spread of non-native species, it is unlikely that the situation of "too much" habitat would ever arise. Natural habitats and native fish and wildlife communities are critical to maintaining ecosystem health. Numerous policies, regulations and ongoing management efforts address habitat-related issues, including RAPs, LaMPs, North American Waterfowl Plan, Great Lakes Fish Community Goals and Objectives, and others. These protection and restoration plans are generally directed toward establishing environmental conditions that support self-sustaining populations of native species and natural communities. "Enough" habitat is therefore determined by the presence and maintenance of healthy native plant and animal communities.

Climate Change
Management Challenge: Given the findings of climate change science, how will managers prepare for potential climate change impacts?

The Union of Concern Scientists report on climate change in the Great Lakes (*Confronting Climate Change in the Great Lakes Region*, www.ucsusa.org/greatlakes/pdf/ex_sum.pdf) and other similar studies suggest that climate in the Great Lakes region is changing. Climate change has the potential to impact Great Lakes water levels, water and air temperatures, ice duration on the lakes, the amount and type of precipitation, habitats for biological diversity, and human land uses such as agriculture and forestry. In order to manage the impacts of a changing environment, climate change needs to be considered during long-term planning (including investments in infrastructure, public health, coastal development, etc.). A management challenge is to evoke management action to adapt to the potential impacts of a changing climate.

Toxic Contamination
Management Challenge: How will the economic and practical issues of continuing the removal of toxic contamination from our ecosystem be addressed?
Management Challenge: How will we determine when and to what extent to monitor specific chemicals and those of emerging concern?

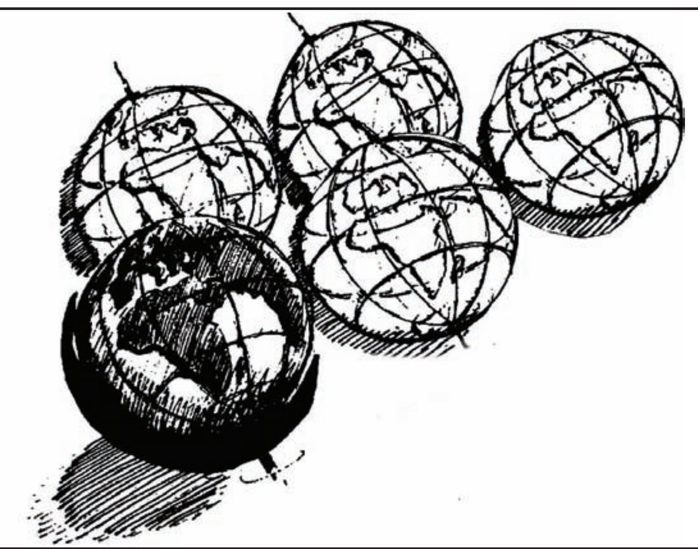
The Great Lakes community achieved significant progress in its more than 30-year effort to remediate toxic contamination in water, fish, sediments, air, and people. Loadings of contaminants to the lakes have been dramatically reduced from their peaks in the 1970s, although problems still exist. Reductions in non-point source runoff have been significant, but optimal reductions are not yet being achieved. Adopting alternative agricultural practices to reduce runoff of pesticides and fertilizers may require a mix of approaches, including voluntary measures and incentives. Controls on industrial emissions of contaminants have been legislated and enforced, resulting in reductions in levels of contaminants in the environment. A management challenge is to economically and practically continue to remove toxic contamination and excess nutrients from the ecosystem and prevent additional loads to the system. The health effects of multiple contaminants, including endocrine disrupting chemicals, pharmaceuticals, other chemicals of emerging concern, and legacy chemicals, need to be addressed. Participants at SOLEC 2006 will focus on these issues as they consider chemical integrity in the Great Lakes basin.

Information Management
Management Challenge: Given the large number of indicators needed to assess the status of the Great Lakes basin ecosystem, how can the findings be sorted, interpreted and shared in a way that is expedient and productive for managers?

Managers require compilations of indicator information to be adequately informed to make environmental management decisions. A challenge is to find a method for compiling or indexing groups of indicators in such a way that leads to their maximum usefulness. Indicator categories are one way to convey ecosystem status to Great Lakes managers and to the public.

A challenge to managers of data/monitoring programs is how to assess and present information for a variety of end users. Issues of data availability and accessibility, linkages and integration of data sources, the scalability of information from local to basin-wide areas, and the specification of measurable endpoints are all vital in order for the information to be useful to environmental decision-making. For example, SOLEC organizers have found that an indicator assessment of "mixed" is not particularly useful to management decisions or the allocation of limited resources without further elaboration of which environmental components need improvement.

The current set of categories does not exclude the possibility of reorganizing indicators into different categories or indices to meet a manager's needs. For example, one approach to analyze the resource utilization category is the "Ecological Footprint." One of the originators of the approach, Dr. William Rees (*Our Ecological Footprint* 1996), estimated that the footprint of the Great Lakes basin, or the area of Earth required to support the current lifestyle of Great Lakes basin citizens, would be equivalent to more than five times the actual area of the basin. In other words, if every person on earth today enjoyed the same type of lifestyle that most Great Lakes basin citizens enjoy, we would need an additional four earth-like planets to accommodate everyone sustainably! Similar "index"-type approaches may be reported in future *State of the Great Lakes* reports.



Source: Rees, W., and Wackernagel, M. 1996. *Our Ecological Footprint: reducing human impact on earth*. Gabriola Island, BC: New Society Publishers.

3.0 Lake and River Assessments

This section of *State of the Great Lakes 2005* provides a summary narrative of the state of each of the five Great Lakes, the St. Clair-Detroit River ecosystem, and the St. Lawrence River. Each narrative also includes an overall assessment based on reviews of available scientific data, reports, and the best professional judgment of the involved scientists and policy makers, along with the information provided in the indicator reports found in the section 4.0. These assessments were provided by primary authors with consultation among the various agencies, groups and organizations involved in the ecosystem management of these large water bodies.

The same status and trajectory ranking categories have been used to give an overall assessment of each water body.
Four broad ranking categories were used to characterize the assessments:

In addition to the assessments and summary narratives, the reports also include a discussion of the pressures on the system, and future and emerging management issues. An underlying emphasis on "physical integrity" throughout the reports reflects the overall theme for SOLEC 2004.

The Lake Erie and Ontario assessment reports also contain a status report on the fisheries within each of these lakes. Each year the Great Lakes Fishery Commission focuses their reporting on one of the Great Lakes. Since SOLEC occurs on a 2-year cycle, the two most recent lake reports are provided to SOLEC participants on behalf of the Great Lakes Fishery Commission. Please note, the Lake Ontario fishery report is a separate piece whereas the Lake Erie fishery report is included in the Lake Erie summary.

3.1 St. Lawrence River

Assessment: The physical integrity of the St. Lawrence River is *mixed*.

The St. Lawrence River flows to the Atlantic Ocean and is the main outlet of the Great Lakes. It was one of the first areas settled in North America. Since the arrival of the European settlers in the 17th century, the river has undergone major structural changes to its course, its hydrodynamics and its resources. About 5 million people live along its shores in Quebec, and in smaller communities along the New York and Ontario sections of the river. The river is the primary navigational access route for trade and commerce in the Great Lakes basin. Ten thousand registered vessels move nearly 100 million metric tonnes of goods on these waters to inland ports every year, although vessel traffic has declined in recent years. As a result of both historical and present day human activities, the river's natural ecosystems have been negatively impacted. The St. Lawrence River has two Areas of Concern (AOCs) at Cornwall, Ontario and Massena, New York (Figure 1).

A unique characteristic of the river is the presence of three distinct water masses that flow side–by–side down to Donacona, some 70 kilometres upstream of Quebec City. The Great Lakes water (green water) is the centre water mass with the Ottawa River, north shore tributaries water mass, or brown water, located on the left bank and the south shore tributaries water mass located on the right bank. Downstream of Donacona, strong tidal forces enable the complete mixing of the water column. Such flow characteristics have tremendous effects on the structure of biological communities. The extent of the impacts of the numerous structural changes, particularly the dredging of the shipping channel, on the flow of the three water masses, is not known.

Structural Changes

Modifications to the river occurred for many reasons including:

- expansion of fertile grounds for agricultural purposes in the flood plains;
- protection from floods and ice jams;
- meeting the demands of urban development;
- maintaining the shipping route; and
- generating hydroelectric power.

Structural changes to the St. Lawrence River, the most important of which are the construction of dams for hydroelectric power and the St. Lawrence Seaway are by far the most important hydrodynamic alterations to this system. A lacustrine environment has now replaced a series of daunting rapids. During the construction of the Seaway, seven villages were flooded, affecting an area of over 260 km^2 and 6,500 people were forced to move from this area as a result of the establishment of these dams. Lake St. François' mean water level, downstream of the dam was raised by 1 metre but its level is now stabilized. Further downstream, the Beauharnois Canal (21 kilometres long, 1 kilometre wide and 9 metres deep) has diverted 86% of the flow over 25 kilometres of the original river bed. The shipping

Figure 1. St. Lawrence River
Source: Environment Canada

channel between Quebec City and Montreal has been deepened and widened, especially in the last century. Hundreds of millions of cubic metres of sediments have been excavated and dredged for the above activities, resulting in major changes to habitats, and the re–introduction of contaminants into the water column (Figure 2). Sedimentation and erosion patterns have also changed as consequences of these structural changes.

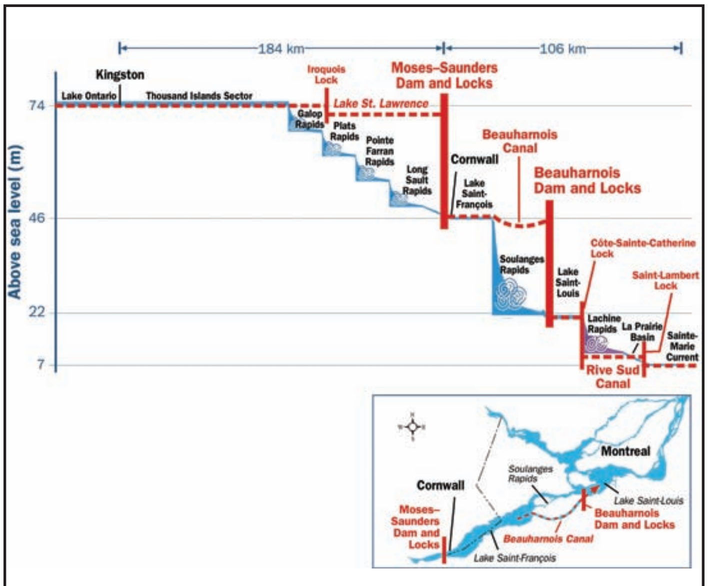


Figure 2. Structural modifications (up until 1959) following the construction of the St. Lawrence River Seaway and the hydroelectric power dams. Historical conditions appear in blue and present day conditions appear in red.
Source: Environment Canada

Shore hardening due to municipal and industrial development, as well as the construction of highways, has also impacted the physical integrity of the river. Most of the shores around the Hochelaga Archipelago (Montreal, Laval, Perrôt and Bizard Islands), a very dynamic milieu at the confluence of the St. Lawrence and the Ottawa Rivers, are now hardened. This area includes more than half of the population of the province of Quebec. Trois–Rivières and Quebec City show similar patterns of shore hardening.

Shore erosion is a natural process, but commercial and recreational navigation, climate change and urbanization may intensify the process. On the north shore of the Gulf of St. Lawrence, towns and villages are located in coastal plain deltas. The absence of ice forming along the shoreline for the past few years has resulted in increased erosion in these deltas. In order to protect properties and highway infrastructure, shores have been hardened over several kilometres, and protected with additional wave breakers, with the added consequence of more severe erosion occurring downstream of these structures.

In the Gaspesie Peninsula, the regional road is built at the bottom of siltstone cliffs and as a result, it is subject to floods during storm surges which exacerbate the erosion process.

Hydrodynamic Alterations of the St. Lawrence River
Structural changes upstream of Montreal, as mentioned above, have drastically and permanently modified the river from a fast water river to a lacustrine flow.

In Lake St. Pierre, prior to dredging, strong currents were limited to the channels at the head and the mouth, while a wide area at the centre of the lake, showed fast moving waters with the weakest currents limited to the nearshore. The dredging of an 11.3 metre deep and 230 metre wide shipping channel has drastically changed the hydrodynamic of the lake. The water flow is mainly restricted to the shipping channel with much reduced currents on each side, and even wider zones of weak currents by the shores. This situation has worsened in years of low discharge. Important variations in water level and velocity bring about major changes in wetland plant communities from low marsh to forested swamp areas.

Alterations to the Shoreline
From Cornwall to the downstream end of Montreal Island, approximately 80% of the shores are hardened and 20% are natural. The reverse situation occurs in the fluvial sector, down to the outlet of Lake St. Pierre, where 80% of the shores are natural. Downstream to Quebec City, the ratio of hardened to natural shores is 40:60. The most severe erosion is observed on the islands of the fluvial sector between Montreal and Lake St. Pierre. This erosion is mostly due to navigation and overall disruption of the sediment dynamics in the system. Around Montreal Island, hardened shores due in large part to urbanization have resulted in major losses of wetlands and accompanying biological communities.

Severe coastal erosion in the St. Lawrence Estuary and Gulf due mainly to climate change will require difficult social and economical decisions in the near future. Costly shore protection structures are not resistant to winter storms and these storms can threaten those living and driving in the area.

Alterations to Habitats and Biological Resources
It has been demonstrated that the invasion of non–native species may be facilitated by man–made or natural disruptions. It has been estimated that the relative plant cover occupied by exotic species in wetlands is high (42–44%) from Lake St. Louis to Contrecoeur. Common reed and reed canary grass clearly have a strong impact on plant diversity. The exponential distribution of a European species of common reed in the Boucherville Islands

Component	Indicator (reference years)	State: Poor	State: Intermediate	State: Good
Water	Water level and flow (1932–2002)	?	?	?
	Contamination by toxic substances, fresh water (1995–2002)			
	Physico-chemical and bacteriological parameters, fresh water (1995–2001)			
	Oceanographic processes, estuary and gulf (multiple–2001)			
	Water quality in potential swimming areas, fresh water (1999–2001)			
	Shellfish area water quality (1988–2002)			
Sediments	Contamination of sediments by toxic substances, Lake Saint-François (1979–1999)			
Biological Resources	Wetlands and exotic plants (1976–2002)			
	Freshwater fish communities (1995–1997)			
	Contamination of freshwater fish by toxic substances (1976–1995)			
	Contamination of marine resources by toxic substances (1990–2001)			
	Great Blue Heron (1977–2001)			
	Seabirds (1925–1999)			
	Northern Gannet (1887–2001)			
	Beluga Whale population of the estuary (1988–2000)			
	Reintroduction of Striped Bass (2002 on)		To follow	

Figure 3. State of the St. Lawrence Monitoring Program assessment of environmental indicators from 2003.
Source: Environment Canada

just downstream of Montreal is a good example. Very dense beds of this non–native species, hinders the establishment and growth of naturally occurring vegetation and may threaten local bird and fish populations.

Management Implications

Provincial and federal governmental departments have united their expertise for the implementation of a long–term environmental monitoring program. A series of indicators pertaining to water quantity and quality, sediment quality as well as diversity and condition of biological resources at the habitat, community and species level serve as a tool to assess the state of the ecosystems from the Quebec–Ontario border to the Gulf of St. Lawrence. Results show that since the 1970s, toxics have decreased in water, sediments and biota, some endangered animal populations have been re–established or will soon be, marine organisms and fresh water fish are safe to eat and losses of wetlands have decreased (Figure 3). However, there are still concerns, such as water use restrictions due to bacterial contamination, chemicals of emerging concern, long–term and cumulative impacts of toxics and invasive species.

Despite the major structural modifications to its physical environment, the river still shows strong resilience to pressures as seen by the encouraging signs of improvement in environmental conditions. However, there are many pressures in the St. Lawrence ecosystem that need to be addressed.

Acknowledgments/Sources of Information

Jean–François Cantin, Jean Morin, Christiane Hudon and Martin Jean from Environment Canada provided the information on hydrodynamics, wetland plant communities and invasive plants species.
François Morneau from Ministère de la Sécurité publique du Québec provided data on shoreline erosion in the Estuary and the Gulf of St. Lawrence.

Saint–Laurent Vision 2000. Monitoring the State of the St. Lawrence River: State of St. Lawrence Monitoring Program. http://www.slv2000.qc.ca/plan_action/phase3/biodiversite/suivi_ecosysteme/accueil_a.htm, last accessed June 7, 2005.

SOLEC 2004 Presentation, Toronto, Ontario. 2004. *St. Lawrence River*. http://www.epa.gov/solec/solec_2004/presentations/index.html, last accessed June 7, 2005.

St. Lawrence River Statistics	
Elevation	Kingston
	246 ft. 75 m
	Lake St. Francis
	151 ft. 46 m
	Lake St. Louis
	66 ft. 20 m
	Montreal
	18ft. 5.5 m
Length[a]	
miles	599
kilometres	964
Mean Annual Discharge[b]	
$ft.^3/s$	44,965
m^3/s	12,600
Land Drainage	
Area[c]	78,090
sq.mi.	204,842
km^2	
Water Surface Area[d]	
sq.mi	6,593
km^2	17,077
Shoreline Length	North Shore
	305 mi. 490 km
	South Shore
	280 mi. 450 km
Transient Time[e]	
hours (minimum)	100
Outlet	Gulf of St. Lawrence

[a] Length of 964 km is from Kingston to Pointe-des-Monts
[b] The mean annual discharge of 12,600 m^3/s is at Quebec City level
[c] The land drainage area of 204,842 km^2 represents the freshwater section in the Quebec Region (Cornwall to Orléans Island)
[d] Total water surface area from Cornwall to Pointe-des-Monts
[e] The transient time applies to Quebec and does not include New York State and Ontario
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Source: The River at a Glance, Environment Canada – Quebec Region

3.2 Lake Ontario

Assessment: The status of the Lake Ontario ecosystem is *mixed.*

Lake Ontario is an ecosystem in transition. Over the last hundred years, the lake has been subjected to a number of stresses including urban development, over fishing, nutrient enrichment, contaminant discharges, introduction of non–native species (e.g. alewife and sea lamprey), and water level regulation. These stresses have led to the degradation of water quality, the loss of fish and wildlife habitat and the decline of native fish communities. While the ecosystem has shown a remarkable capacity to respond and repair this damage, new stresses continue to affect the lake including introductions of non–native species, land use changes and increased population growth.

Background

Lake Ontario is the last in the chain of Great Lakes. Lake Ontario is also the smallest of the Great Lakes in terms of surface area, although it is relatively deep, with an average depth of 84 m, and a water retention time estimated to be about seven years. Over 80% of the water flowing into Lake Ontario comes from the upper Great Lakes through the Niagara River.

More than eight million people live in the Lake Ontario basin, concentrated in the northwest part of the Canadian shoreline. This region, commonly referred to as the "Golden Horseshoe", is highly urbanized and industrialized. The U.S. side of the lake is not as heavily populated, although there are concentrated areas of urbanization at Rochester, Syracuse and Oswego, New York. Outside of these areas, agriculture and forests dominate the land uses within the basin. The forested areas, however, are mainly in the northernmost and easternmost areas of the watershed and forest habitat is highly fragmented closer to the lake.

Figure 1. Lake Ontario drainage basin.
Source: Environment Canada

There are nine Areas of Concern (AOCs) in the Lake Ontario basin, including the Niagara River AOC (Figure 1). The causes of impairments within the AOCs are being addressed and fish and wildlife habitat, populations, and environmental quality are slowly recovering. In the heavily urbanizing areas (for example, the Golden Horseshoe), the gains being made by restoration efforts and management action may be offset by development pressures.

Contaminants

Canada and the U.S. have worked together to ban and control contaminants such as PCBs, DDT, mirex, dioxin/furans, mercury and dieldrin from entering the Great Lakes. As a result of these management actions, levels of contaminants in the Lake Ontario ecosystem have decreased significantly over the last 20–25 years. Recent findings indicate that the management of these critical pollutants has been effective in reducing their presence in the ecosystem, and that fish and wildlife have responded positively in terms of increased population numbers and healthier offspring.

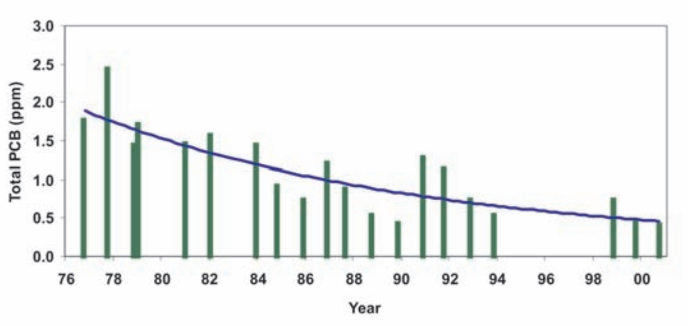

Figure 2. Total PCB levels in 50 cm coho salmon from the Credit River, 1976-2001.
Source: Ontario Ministry of the Environment, A. Todd and A. Hayton, unpublished data

Critical pollutant levels in fish tissue have shown a significant reduction (Figure 2). For example, levels of critical pollutants in Lake Ontario coho salmon have been declining steadily with PCB levels decreasing by 66% and a reduction in mirex concentrations by 50%. However, levels for some contaminants still exceed fish consumption guideline limits.

Levels of contaminants in herring gull eggs have also decreased dramatically (Figure 3). In the 1970s, fish–eating birds in Lake Ontario were found to have very high levels of contaminants in their eggs. Some species exhibited much thinner eggshells than normal, elevated rates of embryonic mortality and deformities, total reproductive failure, and declining population levels. Most of these conditions have improved greatly as contaminant levels have declined, successful reproduction is occurring and population levels have generally increased. These encouraging results suggest that the food base for fish–eating birds in Lake Ontario is becoming less contaminated.

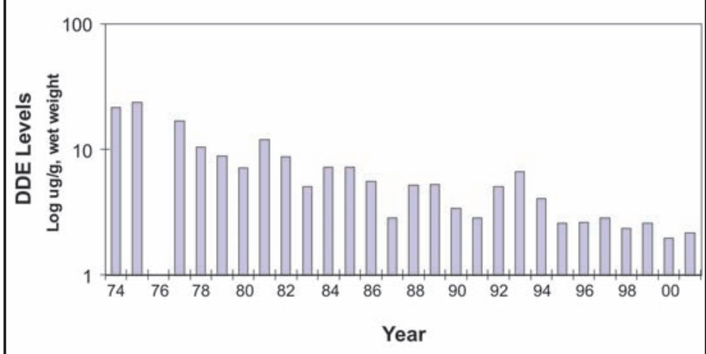

Figure 3. DDE levels in herring gull eggs from Kingston Harbour, 1974-2001.
Source: Data from 1974 to 1992, Bishop *et al*., Pettit *et al*., 1994; data from 1994-2001 from Canadian Wildlife Service, unpublished data

However, there are chemicals of emerging concern in the Lake Ontario ecosystem including polybrominated flame retardants (PBDEs) and the impacts of these chemicals on the Great Lakes are still being evaluated. For more information related to contaminants in fish, refer to the Great Lakes Indicator report #121, Contaminants in Whole Fish, found in this report.

Some fish and wildlife populations once on the verge of extinction have rebounded. Populations of fish–eating waterbirds on Lake Ontario have recovered and are reproducing normally. Caspian terns, common terns, gulls and cormorants have all benefited from the reduction of pollutants. Several key indicator species such as the bald eagle, river otter and mink are also making a comeback in the Lake Ontario ecosystem. Aquatic communities, however, are still under stress from other factors. For an update on the state of aquatic communities in Lake Ontario refer to the Lake Ontario Fishery assessment found in this report.

It appears that the most significant source of some critical pollutants to Lake Ontario now comes from outside the Lake Ontario basin. Upstream sources are responsible for most of the PCBs, DDT and dieldrin that enter the lake. Most of the mirex in Lake Ontario comes from the Niagara River basin.

Fish and Wildlife Habitat

Loss of fish and wildlife habitat is a lakewide problem caused by artificial lake level management, the proliferation of non–native species, and the physical loss, modification or destruction of habitats. Two major power facilities located on the St. Lawrence

River obstruct upstream/downstream fish passage and have impacted fish community structure as well.

There has been a long history of loss, modification or destruction of habitats in Lake Ontario dating back to colonial times. This destruction of land includes deforestation and the damming of tributaries and streams. Before European settlement nearly the entire Lake Ontario watershed was forested.

Wetlands provide vital habitat to many of Lake Ontario's wildlife species. It is estimated that about 50% of Lake Ontario's wetlands throughout the basin have been lost with the intensively urbanized coastlines, losing 60 to 90% of their wetlands. These losses are a result of multiple effects associated with urban development and human alterations, such as diking, in–filling, dredging, and disturbances by public utilities.

Water Level Regulation

Lake water level regulation has seriously impacted Lake Ontario's natural resources, including fish and wildlife, shoreline habitat and dune barrier systems, and the numerous wetland complexes along the shoreline.

The artificial management of lake levels has inadvertently reduced the area, quality, and functioning of Lake Ontario nearshore wetlands. As a result of lake level regulation, Lake Ontario wetlands are no longer experiencing the same range of periodic high and low water levels. This reduction in range has resulted in some wetlands becoming a monoculture of cattails which has greatly reduced the biodiversity of nearshore areas.

Non–native Species

Over the last decade zebra and quagga mussels have significantly disrupted Lake Ontario's aquatic foodweb. Key native benthic organisms vital to the health of fisheries disappeared in the years following the arrival of these exotic mussels. These changes threaten efforts to restore naturally reproducing populations of native lake trout and have severely impacted the whitefish commercial fisheries.

Zebra and quagga mussels have changed many aspects of the physical habitat of Lake Ontario. Their filtering activities have greatly reduced the amounts of material in the water column, thereby increasing light penetration. Increased light penetration has, in turn, allowed re–growth of extensive macrophyte beds in many littoral areas. The innumerable shells released as the mussels die have modified onshore and nearshore habitats, creating shell beaches, that in many cases have smothered shoreline boulder complexes by filling in most crevasses and fissures in rock formations. Colonies have coated many harder surfaces as well, encrusting many man–made features. In littoral and sublittoral areas, colonies have formed clumps and piles over soft substrates, creating structured habitats for other macrobenthos and holdfasts for algae. Deeper still in the water column, the quaggas have formed colonies that sit on top of mud substrates. In fact, it is believed that the changes brought about by zebra and quagga mussels in the lake will persist and may be compounded by the arrival of additional invasive species.

These non–native mussels have not only affected the physical habitat of the lake, but they have also dramatically impacted the lake's biological and chemical integrity. The zebra and quagga mussels filter water to feed on microscopic phytoplankton and other organic material, thereby reducing the amount of food available to other benthic organisms. As a result, populations of important native benthic organisms have generally declined, and this reduction has created a ripple effect that has affected the health of the fisheries and the pathways and fate of toxic chemicals in the foodweb.

As new exotic species continue to be introduced from ballast water from overseas shipping and other sources, the potential for

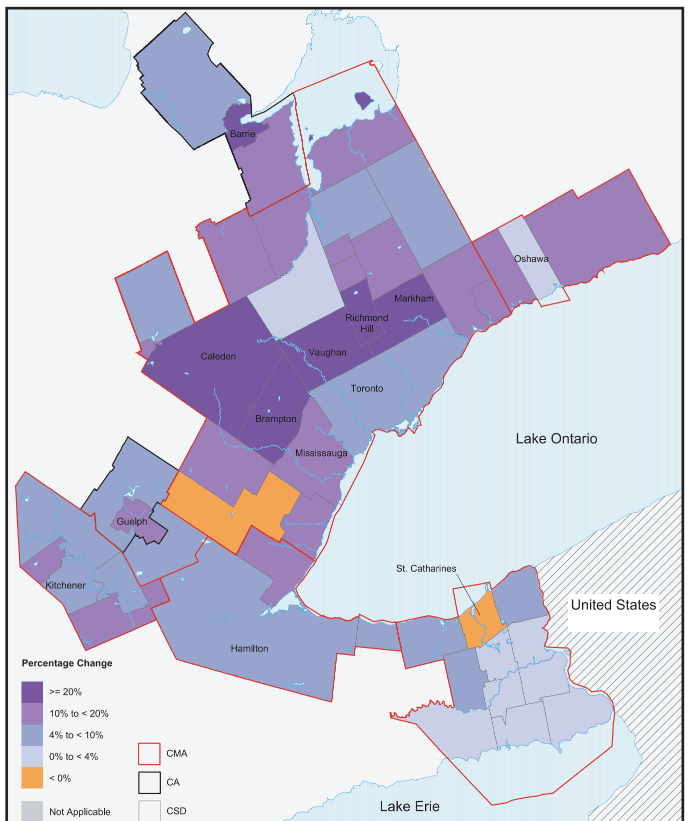

Figure 4. Extended Golden Horseshoe population change, 1996-2001 by 2001 Consensus Subdivision.
Source: Statistics Canada Census, http://geodepot.statcan.ca/Diss/Maps/ThematicMaps/Population/Regional/Horseshoe_popchg_E.pdf, July 20, 2005.

impacts from other non–native species is considerable. Some recently introduced species in Lake Ontario, such as a fish called the round goby and a zooplankton species called the fishhook water flea have taken advantage of the unstable conditions in Lake Ontario and have expanded rapidly as well.

Interactions between zebra and quagga mussels with the round goby may have created conditions that favour the growth of Type E Botulism. Botulism was a major problem on Lake Erie in recent years and has recently been detected at a few locations along the Lake Ontario shoreline. The effects of Type E Botulism were seen during the summer of 2004 on the northeast shores of Lake Ontario.

Urbanization

On the Canadian side of the Lake Ontario basin, land use and population growth are enormous stresses on the system. Human populations are increasing very rapidly and so is low–density urban sprawl. This rapid urban growth is projected to continue around Toronto and into the Hamilton–Niagara region and will result in the loss of large areas of farmland and natural habitats. Between 1996 and 2001 more than 90% of Ontario's population growth took place in this region. By 2030, it is projected that three million more people will live in the Lake Ontario basin with almost all of the growth concentrated in the western end of the lake. This region's population will grow from 7.4 million in 2000 to 10.5 million in 2031; an increase in population of 43%. In fact, this is the third fastest growing area in North America and one of the top 10 most "sprawling" regions in the world. Over the next 30 years, a loss of 1,000 km^2 of primarily agricultural land is forecasted for the Golden Horseshoe if current development trends continue. This newly urbanized area is almost double the area of Toronto and represents a 45% increase in the amount of urbanized land in the region.

The absolute growth in population is of concern in the Golden Horseshoe, but equally important is the nature of that growth (Figure 4). The fringe development is sprawling and is consuming two to three times more land per person than neighbourhoods in the "old" City of Toronto, i.e. prior to amalgamation in 1998. Rural areas are changing as well, with larger farms, fewer farmers, and many more country homes in rural subdivisions or scattered lots. Because these residential uses are often located within scenic natural areas, conflict often exists with wildlife habitats. Overall, the large quantities of land consumed per person through urbanization have resulted in increases in the amount of impervious land area, increases in vehicular travel and transportation related emissions and increases in stormwater runoff.

Figure 5 illustrates the future growth areas in southern Ontario. With these development pressures, it will be very difficult, if not impossible to maintain the recommended 30% natural cover guidelines at the western end of Lake Ontario. It is important to note, however, that these growth pressures are not being felt on the U.S. side of the basin, where only modest increases in population are forecasted, i.e., between 2000 and 2020, a 3.7% increase in population is predicted.

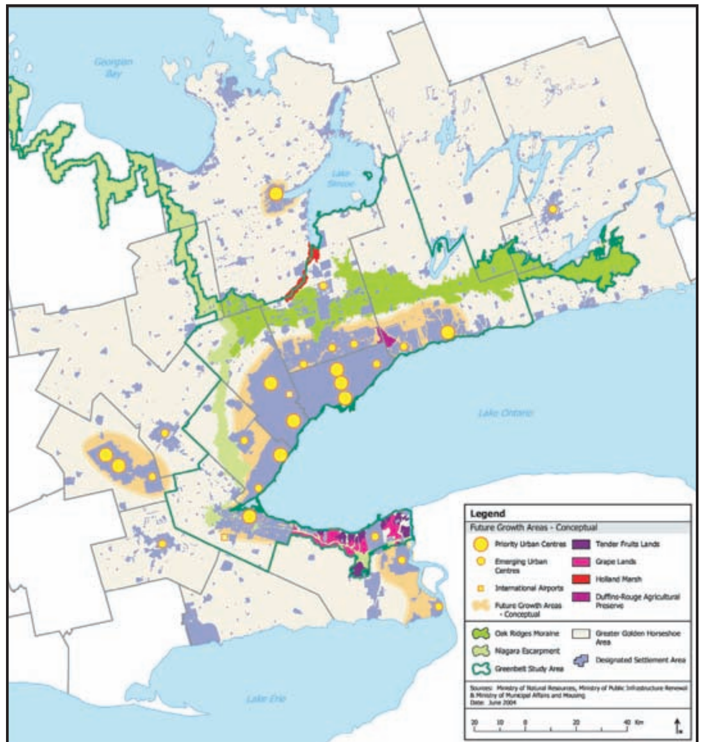

Figure 5. Proposed areas of future growth in Ontario - conceptual.
Source: Ministry of Public Infrastructure Renewal, 2004

Future and Emerging Management Issues

Non–native species will continue to pose problems for the Great Lakes basin and from a management perspective, the future is uncertain. Once a non–native species is introduced, it disrupts the foodweb and creates a ripple effect. It is impossible to improve the conditions in Lake Ontario back to its original state as the effects caused by non–native species are irreversible. The key is to prevent non–native species from entering the Great Lakes.

Continued growth and development in the Lake Ontario basin cannot be stopped. The challenge will be to design communities to accommodate more people without allowing rampant urban sprawl and to allow for the protection of nature for future generations.

Acknowledgments/Sources of Information

Government of Ontario, Canada. Ministry of the Environment. http://www.ene.gov.on.ca/, last accessed June 9, 2005.
Government of Ontario, Canada. Ministry of Public Infrastructure Renewal. http://www.pir.gov.on.ca/, last accessed June 13, 2005.

Government of Ontario, Canada. Ministry of Public Infrastructure Renewal. 2004. *Places to Grow: Better Choices, Brighter Future*. Discussion Paper. http://www.pir.gov.on.ca/userfiles/HTML/cma_4_35655_1.html, last accessed June 13, 2005.

Reid, R. 2001. *Status and Trends of Fish and Wildlife Habitat on the Canadian side of Lake Ontario*. Environment Canada, Ontario Region. Toronto, Ontario: Environment Canada.

SOLEC 2004 Presentations, Toronto, Ontario. 2004. *Lake Ontario.* http://www.epa.gov/solec/solec_2004/presentations/index.html, last accessed June 10, 2005.

U.S. Environmental Protection Agency (EPA). 1998. *Lakewide Management Plan for Lake Ontario: Stage 1: Problem Definition.* http://www.epa.gov/glnpo/lakeont/index.html, last accessed June 13, 2005.

U.S. Environmental Protection Agency (EPA). 2004. *Lakewide Management Plan for Lake Ontario:Lake Ontario LaMP update 2004*. http://www.epa.gov/glnpo/lakeont/, last accessed June 13, 2005.

Lake Ontario Statistics	
Elevation[a]	
feet	243
metres	74
Length	
miles	193
kilometres	311
Breadth	
miles	53
kilometres	85
Average Depth[a]	
feet	283
metres	86
Maximum Depth[a]	
feet	802
metres	244
Volume[a]	
cu.mi.	393
km^3	1,640
Water Area	
sq.mi.	7,340
km^2	18,960
Land Drainage Area[b]	
sq.mi.	24,720
km^2	64,030
Total Area	
sq.mi	32,060
km^2	82,990
Shoreline Length[c]	
miles	712
kilometres	1,146
Retention Time	
years	6
Population: USA (2000)[d]	3,383,400
Population: Canada (2001)	6,368,255
Totals	9,751,655
Outlet	St. Lawrence River

[a] measured at low water datum
[b] Lake Ontario includes the Niagara River
[c] including islands
[d] 2000 population census data were calculated based on the total population of each county, either completely or partially, located within the watershed.

Sources:
The Great Lakes: An Environmental Atlas and Resource Book

Statistics Canada, Environment Accounts and Statistics Division, Spatial Environmental Information System and Censuses of Population 2001.

U.S. Census Bureau: State and County QuickFacts. Data derived from Population Estimates, 2000 Census of Population and Housing, 1990 Census of Population and Housing

Lake Ontario Fishery

Assessment: The status of the Lake Ontario fishery is *mixed* and *undetermined*.

The assessment of Lake Ontario fishery indicators is based on a wide variety of dependent and independent field programs. These programs are delivered by several agencies including N.Y. State Department of Environmental Conservation, Ontario Ministry of Natural Resources and the U.S. Geological Survey. Offshore programs include angler creel surveys, bottom trawling surveys, hydroacoustic assessment, gill net surveys and stocking in the lake and its tributaries. Stocking includes fry and fingerlings of salmon and trout. Salmon and trout populations are also monitored in tributaries as they return to spawn and by using angler creel surveys.

The nearshore is dominated by warm–water fish species and the programs used to assess this species range from multi–mesh size index gillnets to bottom trawls to angler creels.

Sea lamprey are monitored by a wide variety of programs focusing primarily on larval and adult life stages. In addition, scarring rates on lake trout caused by juvenile sea lamprey are an important Great Lakes Fishery Commission abundance indicator.

Summary of the State of the Lake Ontario Fishery

The offshore lake ecosystem (>15m depth) is a dynamic and a relatively less species–rich area with respect to the nearshore. The offshore ecosystem continues to rely heavily on introduced salmonines (salmon and trout) to provide fisheries for recreational use and to act as top predators for alewife and smelt (refer to Great Lakes indicator #8, Salmon and Trout, found in this report). The current salmon and trout complex remains reliant on alewife and smelt and these forage species are currently in a mixed or deteriorating state (Figure 1 and 2). In response, the top predators, particularly chinook salmon are showing signs of reduced weight (Figure 3). The pelagic salmonine species i.e. chinook salmon, rainbow trout (including steelhead), brown trout, and coho salmon continue to support a recreational fishery with a high catch per unit effort and are showing variable rates of wild reproduction in many tributaries. Thus, these species are in a fair state but given the forage food base, the population numbers for these fish remains uncertain. Atlantic salmon restoration remains a research initiative. Size–related consumption advisories for a variety of chemicals including dioxins, mirex and PCBs exist for brown and rainbow trout, and chinook and coho salmon in both New York and Ontario waters of the lake and in some tributaries.

Lake trout have shown signs of natural reproduction every year since 1993 but are reliant on stocking to support the recreational fishery. Survival of recently stocked lake trout is poor. Larger lake trout continue to show persistent contaminant issues related to a variety of chemicals including PCBs, dioxins and mirex (Consumption Guidelines, Ministry of Environment 2003, NYSDEC 2002). Sea lamprey scarring rates on lake trout have remained at or below the targeted level of 2 per 100 lake trout. However, the future state of lake trout remains uncertain.

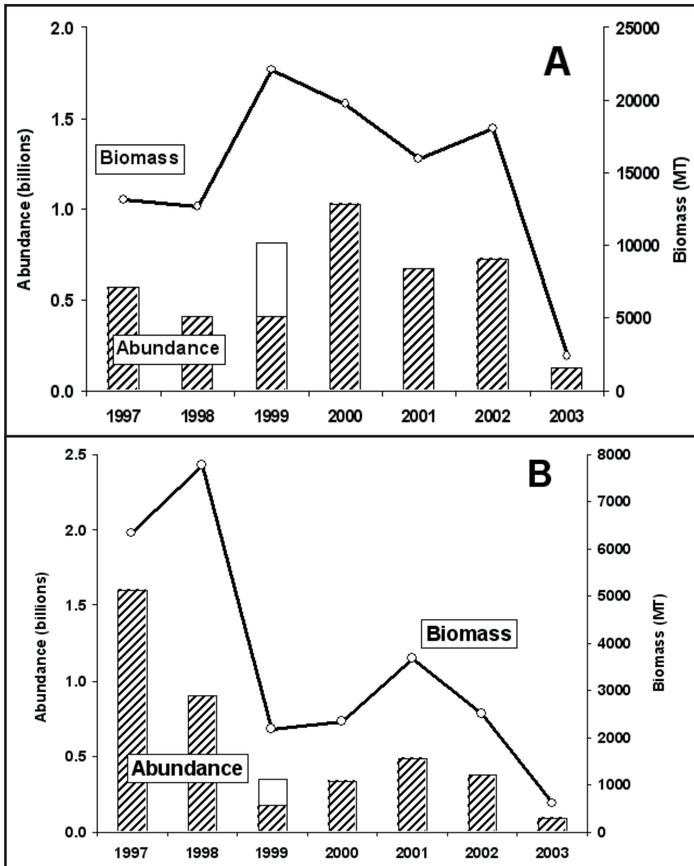

Figure 1A. Abundance and biomass of yearling-and-older alewife.

Figure 1B. Abundance and biomass of yearling-and-older rainbow smelt. Abundance estimates (represented by bar graphs) were derived directly from hydroacoustic surveys; biomass estimates (represented by solid line) were obtained by applying average weights measured in midwater trawls to hydroacoustic abundance estimates. The abundance estimates for 1999 (dark plus light bars) was obtained by doubling the 1999 half-lake estimate (dark bar). Average weights used in biomass calculations in 2002 (alewife) and 2002 to 2003 (smelt) were based on pooled data from other years.

Source: U.S. Geological Survey, 2004

The main indicator species for the nearshore is walleye. In eastern Lake Ontario including the Bay of Quinte, walleye have a relatively stable but much reduced abundance in comparison to

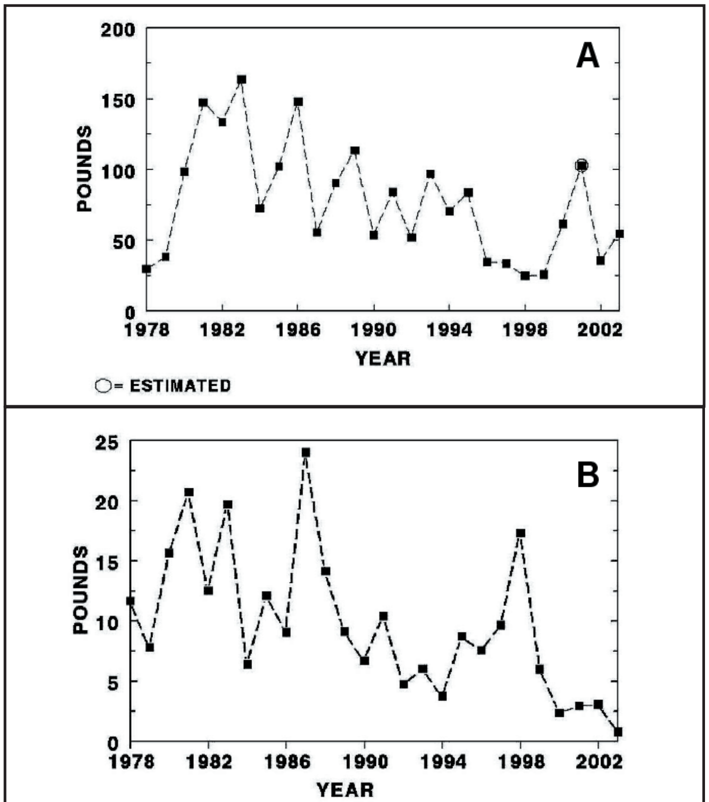

Figure 2A. Stratified mean catch of adult alewives (age 2 and older) in late April-early May, with bottom trawls in U.S. waters of Lake Ontario, 1978-2003. Figure 2B. Stratified mean catch of rainbow smelt (age 1 and older) in June, with bottom trawls in U.S. waters of Lake Ontario, 1978-2003.
Note: 1 lb = 0.45 kg.
Source: U.S. Geological Survey, 2004

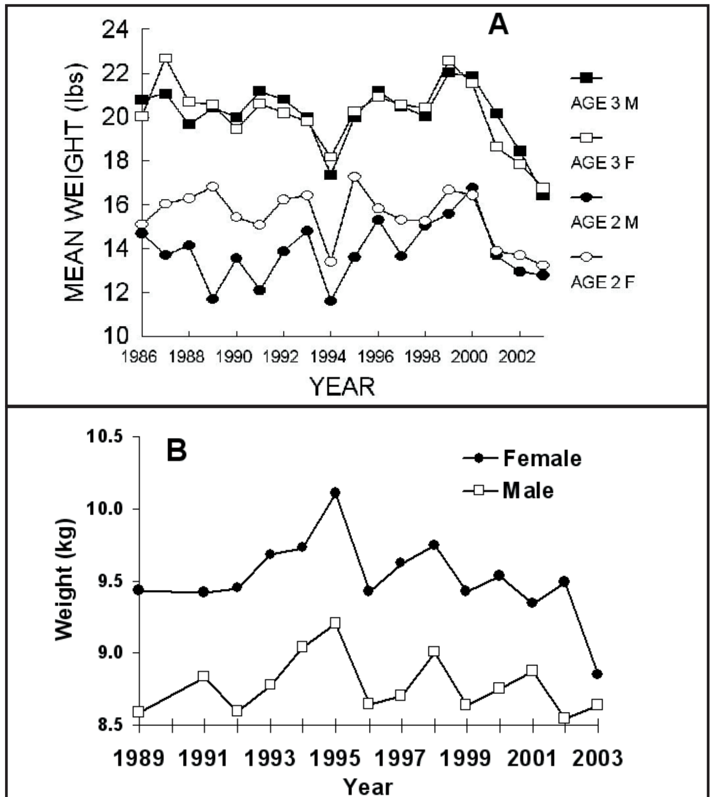

Figure 3A. Time series trends of mean weight (lb) of age 2 and 3 male and female chinook salmon in the Salmon River, New York. Figure 3B. Times series trends of mean weight (kg) of a 900 mm (35.4 inch) chinook salmon in the Credit River, Ontario during the spawning run; approx. October. Note: 1 lb = 0.45 kg. M = Male; F = Female.
Source: N.Y. State Department of Environmental Conservation, Ontario Ministry of Natural Resources, 2004

the late 1980s (Figure 4). Refer to Great Lakes indicator #9, Walleye, found in this report. Walleye are still the number one fish species sought in the Bay of Quinte and for the first time in several years, the effort expended by anglers increased in 2003 (Figure 5). Recruitment of walleye appears to be relatively consistent in recent years. There is a wide range of age classes present in the population. However, alewife are the main prey item for walleye (especially fish older than age 5) and given the poor status of alewife, it is difficult to determine the future population trends for walleye. Fortunately, walleye are less particular about their diet than salmonines. Consumption advisories for mercury exist for walleye greater than 23 inches (approximately 58 cm) total length in the Canadian waters of Lake Ontario. The consumption guidelines for mercury vary between Health Canada and the Federal Drug Administration.

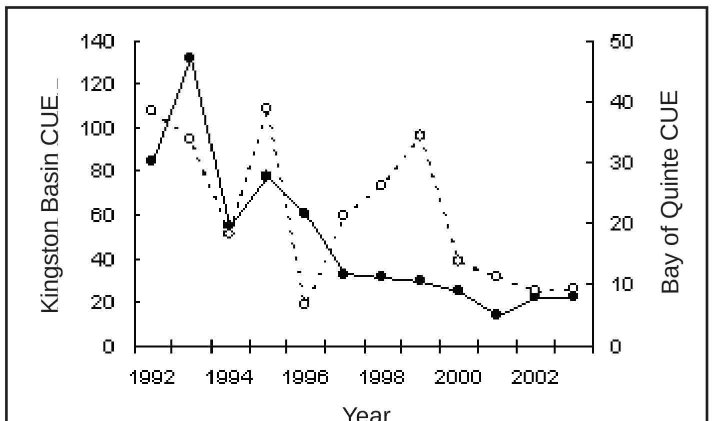

Figure 4. The catch per unit effort (CUE) based on the catch per gillnet set of walleye in the Bay of Quinte (closed circles) and in the Kingston basin, Lake Ontario (open circles), 1992-2003.
Source: Ontario Ministry of Natural Resources, 2004

Pressures on the System
The current pressures on the ecosystem are non–native species, continued colonization by cormorants, fishing pressure, effects

of thiaminase (an enzyme causing early mortality syndrome in salmonines and found in prey fish such as alewife, smelt), continued reliance on stocking, continued changes to both the nearshore and offshore habitat and food web (as indicated by declines in lake whitefish, lake herring, and both slimy and deep water sculpins) and the persistence of contaminants in many fish species including walleye and lake trout. These current pressures will continue as stresses in the future. The list of contaminants affecting the aquatic communities may expand as chemicals of emerging concern, such as PBDE fire retardants, are further identified and analyzed. The pressures caused by introduced salmonines and stocking are described in the Great Lakes indicator #8, Salmon and Trout, found in this report.

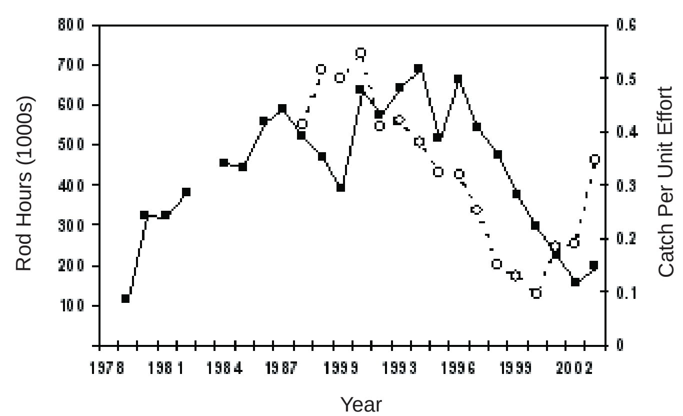

Figure 5. Angling effort, represented by closed squares and catch per unit effort (CUE), represented by open circles, for walleye fishing in the Bay of Quinte, eastern Lake Ontario, 1978-2003.
Source: Ontario Ministry of Natural Resources, 2004

Future and Emerging Management Issues
Research and stocking of ciscoes in Lake Ontario are future activities that could mitigate the effects of thiaminase and in turn, increase the survival of lake trout and Atlantic salmon. The Lake Ontario Committee and the Great Lakes Fishery Commission have completed a research project examining gamete collection for ciscoes and have embarked on a comprehensive restoration effort involving federal, state and provincial partners. Non–native species legislation has been introduced in Ontario and comparable legislation already exists in New York. Amendments to the U.S. Lacey Act would also mitigate the potential for new invasive species in Lake Ontario.

Measures to alleviate the existing pressures on Lake Ontario's fish community are needed.

Acknowledgments/Sources of Information
Government of Ontario, Canada. Ministry of the Environment. http://www.ene.gov.on.ca/, last accessed June 9, 2005.

Government of Ontario, Canada. Ontario Ministry of Natural Resources (OMNR). http://www.mnr.gov.on.ca/, last accessed June 9, 2005.

Great Lakes Fishery Commission. http://www.glfc.org/, last accessed June 9, 2005.

New York State Department of Environmental Conservation (NYSDEC) 2002, and Ontario Ministry of the Environment (OMOE) 2003. Consumption Guidelines.

Sheehan, D.M., Acting Commissioner. New York State Department of Environmental Conservation (NYSDEC). http://www.dec.state.ny.us/website/index.html, last accessed June 9, 2005.

United States Geological Survey (USGS). http://www.usgs.gov/, last accessed June 9, 2005.

U.S. Environmental Protection Agency (EPA). http://www.epa.gov/, last accessed June 9, 2005.

3.3 Lake Erie

Assessment: The status of the Lake Erie ecosystem is *mixed*.

Impacts of changing land use, shoreline alteration, nutrient loading, chemical contamination and non–native species, as a consequence of human activities, continue to affect fish and wildlife populations, habitat quality and quantity and food web dynamics. Contaminant levels in water and sediment continue to decrease, and habitat protection activities have increased in the Lake Erie basin.

Summary of the Status of the Lake Erie Ecosystem

The physical integrity of Lake Erie has a direct bearing on how the lake ecosystem reacts to various stressors. Approximately 80% of Lake Erie's total inflow of water comes through the Detroit River, 11% from precipitation, with the remaining 9% from tributaries flowing through watersheds in Michigan, Ohio, Pennsylvania, New York and Ontario (Bolsenga and Herdendorf 1993). The Niagara River is the main outflow from the lake. Lake Erie, by volume, is the smallest of the Great Lakes, and is second smallest in surface area. As the shallowest of the Great Lakes, it warms quickly in the spring and summer and cools quickly in the fall, making it the most biologically productive of the Great Lakes.

There are ten Areas of Concern (AOCs) closely associated with Lake Erie: the Detroit River (Binational); the River Raison (Michigan); the Maumee, Black, Cuyahoga and Ashtabula rivers (Ohio); Presque Isle Bay (Pennsylvania); Buffalo River (New York); Wheatley Harbour (Ontario); and the Niagara River (Binational). Remedial Action Plan teams have or are currently developing strategies to deal with site–specific contaminated sediment issues at most of these AOCs, but progress is slow. Only one of these sites, the Presque Isle Bay AOC has recently

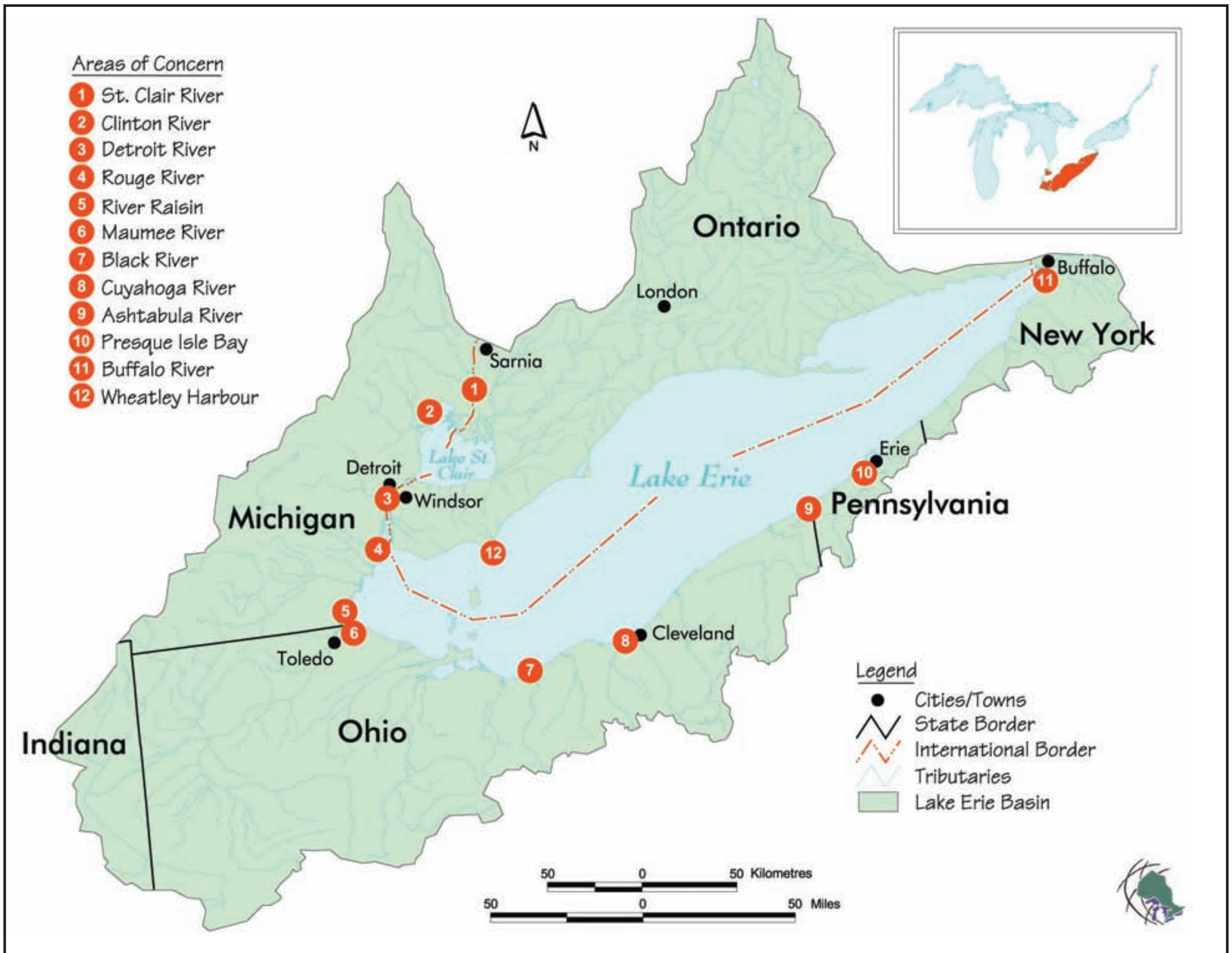

Figure 1. Lake Erie drainage basin.
Source: Environment Canada

been designated as an "Area in Recovery" (Figure 1).

About one third of the total population of the Great Lakes basin resides within the Lake Erie watershed. This amounts to 11.6 million people (10 million American and 1.6 million Canadian), including seventeen metropolitan areas, each with more than 50,000 residents. Many of these metropolitan areas use Lake Erie as a source for drinking water. Continued development and urbanization have led to increased demands for drinking water and requests for diversions of Lake Erie water outside of the basin. The cumulative effects of these diversions are unknown and unless carefully managed, could have significant long–term impacts on surface and groundwater hydrology and ecosystem functions.

Lake Erie is naturally divided into three basins (Figure 2). The western basin is very shallow with an average depth of 7.4 m (24 ft) and a maximum depth of 19 m (62 ft). The central basin is uniform in depth, with the average depth of 18.3 m (60 ft) and a maximum depth of 25 m (82 ft). The eastern basin is the deepest of the three, with an average depth of 25 m (82 ft) and a maximum depth of 64 m (210 ft). Each spring, Lake Erie waters in the central and eastern basins thermally stratify, isolating oxygen–rich surface waters from the cooler, deeper bottom waters. Western basin waters rarely stratify due to the shallow water depths and mixing due to storms. Stratification impacts the internal dynamics of the lake, physically, biologically, and chemically. Thermal stratification in the summer is a natural phenomenon that occurs in many temperate lakes.

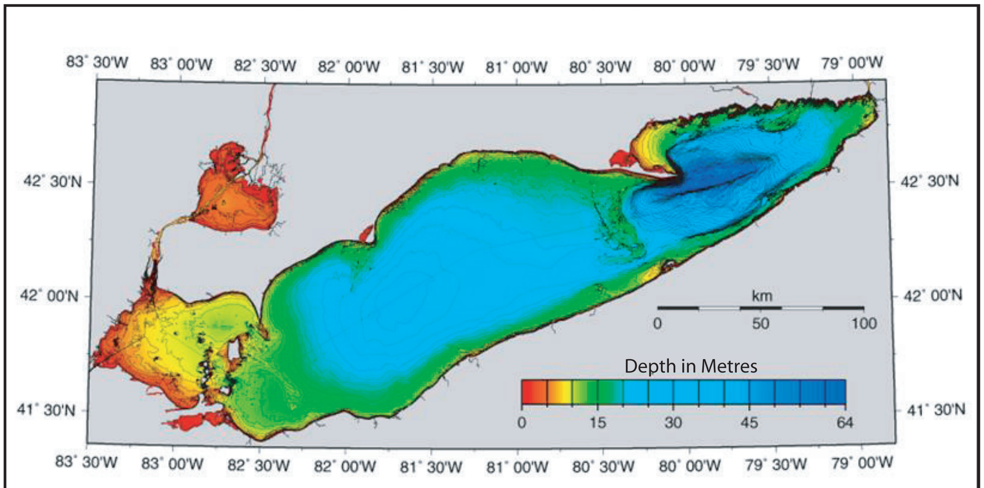

Figure 2. Map of Lake Erie bathymetry illustrating three distinct basins. Eighty percent of Lake Erie's total inflow of water comes through the Detroit River. Bathymetric 1-metre contour intervals are shown.
Source: National Geophysical Data Center, 1998

Even though phosphorus loadings into the central basin have been reduced and are well within target limits, there has been an expansion of an anoxic (oxygen–poor) zone within the central basin over the past several years. The contributory effects of zebra/quagga mussel nutrient recycling in the development of anoxic bottom waters are unknown. However, recent studies (Lam *et al.* 1987, 2002; Charlton and Milne 2004) have shown that oxygen depletion in the waters of Lake Erie's central basin hypolimnion is affected more by its thickness rather than by nutrient loads or invasive species. When a thin hypolimnion develops (e.g. under prolonged solar heating, insufficient wind mixing, and/or lower lake levels), the hypolimnion volume is reduced and strong thermal stratification usually occurs. This stratification prevents the movement of oxygen from the upper layers into the hypolimnion and therefore, oxygen levels that have been depleted by biological oxygen demand (BOD) are not replenished. Anoxic bottom waters adversely affect benthic communities and food web dynamics. Furthermore, anaerobic processes may increase pollutant bioavailability.

Urbanization and intensive agricultural development, particularly in southwest Ontario and northwest Ohio, have contributed to high sediment loads to the lake. Suspended sediment is a pollutant in itself and carries many persistent toxic chemicals as well. Suspended sediments have profoundly influenced the ecology of the western basin and the river mouths of most of Lake Erie's tributaries. Much of the lake bottom is covered with fine sediments that are re–suspended when the shallow lake is disturbed by winds. The western basin is generally the most turbid region of the lake, and much of its sediment load eventually moves into the central and eastern basins. Even though sediment loads are still high, implementation of non–point source programs and the application of best management practices on agricultural lands have reduced daily suspended sediment loads into the lake by more than 50% over the past 20 years (Richards and Baker 1998). Continued reductions in sediment loads will improve the quality and clarity of Lake Erie waters, improve tributary and coastal habitats, and reduce the amount and frequency of materials being dredged in order to maintain navigation channels.

Contaminant loadings and the accumulation of persistent toxic chemicals in water, sediment, fish and wildlife continue to decline. The development of extensive pollution control regulations, improvements in treatment technologies, adoption of stringent water quality standards, bans on production and use of certain chemicals, and pollution prevention has greatly reduced the direct discharge of contaminants into Lake Erie. However, Lake Erie still receives the largest amount of effluent from sewage treatment plants (Dolan 1993). Input from combined sewer overflows (CSOs) continue to be problematic in many metropolitan areas.

Considerable progress has been made in reducing the use of mercury and PCB containing products in the basin, with Canadian and U.S. mercury emissions decreasing approximately 83 and 40% respectively, since 1990. However, atmospheric deposition of contaminants such as mercury, from outside the basin and non–point pollution (nutrients and pesticides) remain problematic. Contaminated sediments containing mercury, PCBs, trace metals, and pesticides are still present in many Great Lakes' waterways and can bioaccumulate through the food chain, impacting the health of fish and wildlife communities and resulting in fish consumption advisories.

Habitat loss and degradation in the Lake Erie basin over the last 200 years has been extensive (Hartman 1973; Bolsenga and Herdendorf 1993; Halyk and Davies 1998). The most pronounced impacts have occurred in tributaries, coastal wetlands and nearshore habitats that are crucial fish spawning, nursery, and food production areas. These coastal systems are comprised of diverse habitats that are interconnected and dependent upon the physical integrity of natural coastal processes to maintain these habitats. Impacts have been most pronounced along the southern and western shore of Lake Erie, where dredging, shoreline armouring, infilling and diking of wetlands, and other shoreline modifications have eliminated land–margin connections, altered substrate and water–mass characteristics and affected natural coastal processes. For example, the shorelines of river mouths and estuaries of Lake Erie are densely industrialized and highly urbanized, eliminating or degrading critical spawning and nursery habitat for a wide variety of fish species.

Loss of historic wetlands in the Lake Erie basin is estimated to be approximately 80%, which has affected Lake Erie hydrology and wildlife and waterfowl habitat (Snell 1987; Maynard and Wilcox 1996). Fortunately, the rate of habitat loss and degradation has slowed dramatically within the past decade with the implementation of more comprehensive habitat protection programs and policies. However, incremental losses of wetlands still occur in both Canada and the U.S.

Erosion control and navigation structures such as breakwaters, jetties, and piers interrupt nearshore sediment transport processes and energy dynamics, change water depths, and alter nearshore circulation patterns and substrates. In 1993, approximately 50% of the Lake Erie shoreline was modified by some type of man–made structure (Figure 3, IJC 1993). In Ohio, recent work by the Ohio Geological Survey has shown that the percentage of hardened shorelines more than doubled between 1970 and 2000 in response to increased shoreline development and erosion caused by near record high Lake Erie water levels. In Ohio, one of the most extensively developed shorelines in the Great Lakes, the percentage of hardened shoreline in 2000 ranged from 62% in Ashtabula County to 98% in Lucas County (Table 1). Given the continuing development pressures on the Lake Erie shoreline, it is likely the percentage of hardened shoreline will continue to increase over the next several decades, although at a somewhat lower rate, as Lake Erie water levels have receded from near historic highs.

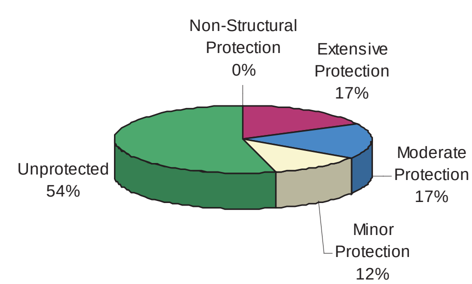

Figure 3. Lake Erie shoreline hardening, Canada and U.S. Source: International Joint Commission

County	Percent Protected Shoreline 1877	1937	1973	2000
Ashtabula	0	8	12	62
Lake	0	5	6	69
Cuyahoga	11	41	37	83
Lorain	0	6	31	79
Erie	0	14	25	87
Ottawa	1	0	25	78
Lucas	0	5	41	98

Table 1. Lake Erie shore protection trends in Ohio counties from 1870-1990. The percentage of protected shoreline more than doubled between 1970 and 2000 in Ohio in response to increased shoreline development and erosion caused by near-record high Lake Erie water levels. Source: Ohio Department of Natural Resources-Ohio

The introduction of zebra mussels in the late 1980s triggered a tremendous ecological change in Lake Erie. Zebra mussels changed the physical characteristics of aquatic habitats and altered food web dynamics, energy transfer, and nutrient and contaminant cycling within the lake ecosystem. Additional non–native species such as the quagga mussel, round goby and several large zooplankton species have further altered the system. Increased water transparency due to the combined effects of nutrient control and filtration by mussel species, have reduced habitat for walleye in the western, central and eastern basins since walleye avoid high light conditions. Furthermore, increased water transparency combined with lower Lake Erie water levels has resulted in an increase of submerged macrophytes (aquatic vegetation) and has increased benthic production. Lake Erie beaches and submerged sediment substrates have also been affected by mussel species with a significant loss of soft substrates on the bed of Lake Erie (Berkman *et al*. 1998). Moreover, the food web is currently in transition. Changes in trophic conditions initiated by loading reductions became a significant problem after mussel species initiated biological oligotrophication by further redirecting nutrients from pelagic production to benthic production (Johannsson *et al*. 2000).

Lake Erie Fish Community

The depth of Lake Erie increases from west to east (Figure 2). Nutrient levels decline along the same gradient, such that the western basin is mesotrophic, the east is oligotrophic and the central basin shows the gradient between them. Thermal environments vary between basins and favour different groups of fish (Kitchell *et al*. 1977). Species in the "cool–water" community have temperature preferences between 20 and 28 degrees Celsius (68 and 82 degrees Fahrenheit), and are usually found in mesotrophic conditions (Hokanson 1977, Ryder and Kerr 1978). Species in the "cold–water" community have temperature preferences of less than 20 degrees Celsius (68 degrees Fahrenheit), and are usually found in oligotrophic waters. Most of the lake volume is classified as cool–water habitat (75% of volume, Christie and Regier 1988), and therefore, the cool–water fish community is dominant. The west and east basins are perceived as the organizational centres for two different fish community types, resulting in the need for management goals for each community as highlighted below (Ryan *et al*. 2001):

- To secure a balanced, predominantly cool–water fish community, with walleye as a key predator in the western basin, central basin, and the nearshore waters of the eastern basin, characterized by self–sustaining native and naturalized species that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem.

- To secure a predominately cold–water fish community in the deep, offshore waters of the eastern basin with lake trout and burbot as key predators.

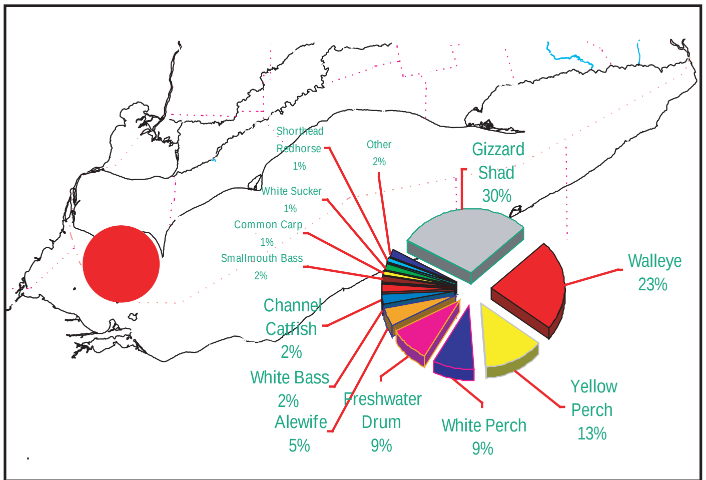

Figure 4. Composition of biomass from survey gillnet catches in the western basin of Lake Erie during fall of 2000. Source: Ontario Ministry of Natural Resources (OMNR) and the Ontario Commercial Fisheries Association in partnership, OMNR 2001.

The biomass composition in western Lake Erie (Figure 4) includes strong representation from the cool–water fish community and some warm–water species (preference greater than 28 degrees Celsius or 82 degrees Fahrenheit). The cool–water community has lost significant biodiversity though the extinction of the blue pike and sauger (Table 2) and by the major decline in the abundance and distribution of lake sturgeon. Lake sturgeon were abundant and formerly distributed lakewide. The current population has been substantially reduced and is rarely seen over most of the lake. It is most common in the western basin.

Walleye stocks have increased beyond their apparent historical abundance. They exhibit migratory behaviour similar to the blue pike and may be providing a similar predator function in the lake. Yellow perch have also increased beyond their apparent historical abundance. The burrowing mayfly is a key benthic

Species	Historical context	Post GLQWA	Status 2004	Comments
Blue Pike	extinct			
Sauger	"regionally extinct"			
Yellow Perch	more abundant	+++	Good	Natural variability
Walleye	more abundant	+++	Poor	Improving
Lake Sturgeon	limited distribution	rare	Poor	Improving
Burrowing Mayflies	limited distribution	+	Mixed	Natural variability
Community Status			**Mixed Improving**	

Table 2. Status of component species and overall community state for cool-water communities in Lake Erie. Code: less than "++++" indicates that the species is below the potential capacity of lake.
Source: Ontario Ministry of Natural Resources

species whose abundance has recovered to near historical levels in major areas of the western basin, where it provides a valuable food supply to percids and other fish species. Walleye and yellow perch both showed strong declines after zebra and quagga mussels colonized the lake, however yellow perch have made a strong recovery beginning in the late 1990s and walleye has begun to recover with stronger reproduction in 2003. Walleye and burrowing mayflies are both indicators of healthy mesotrophic food webs (Edwards and Ryder 1990, Bertram and Stadler–Salt 2000) and both are showing signs of improvement in Lake Erie. The cool–water fish community status is assessed as mixed and improving.

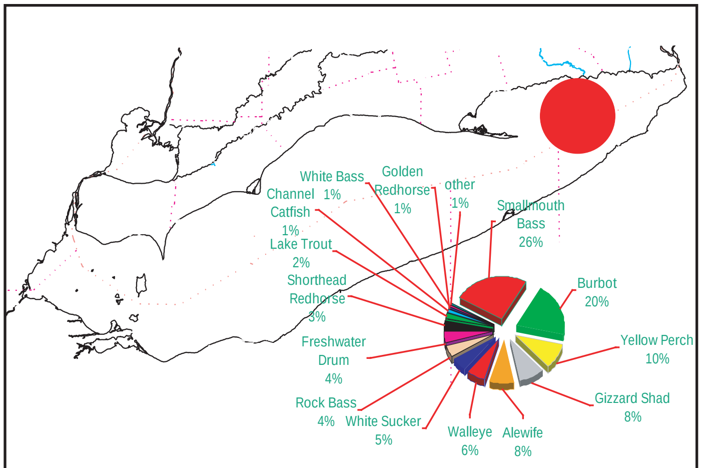

Figure 5. Composition of biomass from survey gillnet catches in the eastern basin of Lake Erie during the fall of 2000. Source: Ontario Ministry of Natural Resources (OMNR) and the Ontario Commercial Fisheries Association in partnership, OMNR 2001.

Species	Historical context	Post GLQWA	Status 2004	Comments
Long-jaw Cisco	extinct			
Lake Herring	rare			
Slimy Sculpin	extinct			
Spoonhead Sculpin	extinct			
Lake Trout	extinct	pre-lamprey control	Stocked	Improving
Deepwater Amphipod	extinct	+++		
Opossum Shrimp	rare		Poor	Undetermined
Lake Whitefish	common	+	Mixed	Natural variability
Burbot	abundant	+	Good	Natural variability
Rainbow Trout			Naturalized/stocked	
Rainbow Smelt			++++	
Alewife			+	
Round Goby			++	
Quagga Mussel			++++	
Community Status			**Mixed Improving**	

Table 3. Status of component species and overall community state for cold-water communities in Lake Erie. Code: less than "++++" indicates that the species is below the potential capacity of lake.
Source: Ontario Ministry of Natural Resources

The biomass of the community in the eastern basin (Figure 5) shows strong representation from cold–water species. The cold–water community has experienced a catastrophic loss of biodiversity (Table 3). Slimy, spoonhead sculpins, deepwater longjaw cisco, shallow–water ciscoes (lake herring), and lake trout have been rare or absent since the 1960s or earlier (Ryan *et al*. 1999).

The cold–water food web is centred in the deep waters of the eastern basin and near–by waters of the central basin which usually maintain sufficient levels of dissolved oxygen during the summer. Some former key invertebrate components of that food web are either rare (*Mysis relicta*, or opossum shrimp) since the 1960s or earlier, or apparently extinct (*Diporeia hoyi*, or deepwater amphipod) since the late 1990s (Dermot and Kerec 1997). These organisms are a food source for all the deepwater fish species for at least part of their life history, in north–temperate lakes (Scott and Crossman 1973), and therefore their extinction represents a critical loss of biodiversity.

In the 1990s, fish biomass in Lake Erie's cold–water habitat was dominated by rainbow smelt, a non–native invasive species. Smelt and alewife, both non–native species, possess high levels of thiaminase which can affect the reproductive success of fish that consume smelt or alewife by impacting the viability of their predator's eggs. Lake Erie's lake trout populations are not self–sustaining through natural reproduction and thiaminase is suspected as a contributing factor (Fisher *et al*. 1996, Fitzsimmons and Brown 1998).

A lake trout stocking program was initiated by the New York Department of Environmental Conservation and the United States Fish and Wildlife Service in the 1970s. Survival of lake trout has improved with establishment of sea lamprey control in the 1980s (Cornelius *et al*. 1995). Similarly, native burbot have also increased in abundance after sea lamprey control was implemented (Markham *et al*. 2004).

Recent stocking strategies to recover lake trout populations involves the selection of genetic strains that are better adapted to Lake Erie's environmental conditions and the release of fish (as sac–fry stage trout) at historical spawning areas to attract fish back to these areas for spawning purposes. Survival of the stocked trout has improved in recent years.

The lake whitefish population increased substantially in the 1980s, and has remained at a higher level of abundance. The deepwater amphipod, *Diporeia*, an indicator species for coldwater or oligotrophic food webs (Ryder and Edwards 1985) that was extirpated in the late 1990s, has shown no sign of recovery. Although there are sporadic reports of lake herring, the status must still be considered "extirpated" (Leach and Nepszy 1976). Most of the native species biodiversity of the cold–water food web has been lost. Functional biodiversity may be making some recovery as more of the Caspian fauna associated with quagga mussels have colonized cold–water habitat. The status of the cold–water community is assessed as mixed.

Warm–water fish are significant components of the local scale fish community including shorelines, river mouths, bays and coastal wetlands.

Lake Erie's fishery is primarily based on wild native fish species (walleye, yellow perch, smallmouth bass and lake whitefish) and on "naturalized" stocks of rainbow trout. The Lake Erie Committee recognizes the stock concept in management: "Stocks (or populations) are the basic unit for conservation and management and should, where feasible, be identified, monitored, and appropriately managed.

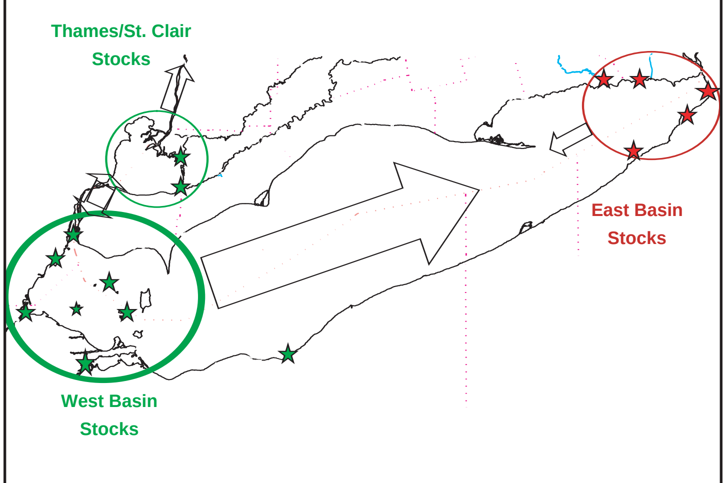

Figure 6. Principal locations for the tagging of adult walleye and the dispersion directions of walleye after spawning.
Source: Haas, R., Michigan Department of Natural Resources, Mt. Clemens Fisheries Research Station, Michigan

A wild fish population, such as the walleye in Lake Erie (Figure 6), must rely upon lake and stream environments to provide suitable conditions for their life cycle i.e. spawning, nursery, juvenile and adult habitats. Over the 6,000 years that Lake Erie has been at the current water level, there has been adaptation to local conditions by the evolution of the population into stocks. Walleye that were tagged from the Grand River, Ohio return there, rather than go to other spawning areas. The "spawning ground fidelity" that these fish show, allows them to adapt to the local conditions. DNA testing determines how similar or divergent walleye stocks are from each other, which is an indication of the level of adaptation and separation between stocks (Stepien 1995).

Because of a long history of tagging studies and the adoption of new technology for stock identification, a great deal of information exists regarding walleye (Todd and Haas 1993). A number of walleye stocks are depressed or have apparently been lost. Poor environmental conditions in tributaries and dams have contributed to loss of stocks and may prevent recovery. The current initiatives under the Great Lakes Water Quality Agreement need to be completed in order to allow recovery or restoration of walleye stocks and other species in the lake. The status of walleye stocks is assessed as mixed and improving.

There was a high level of integration of the Lake Erie ecosystem by fish migrations in the 1800s. Lake herring migrated from the eastern to western basin, and up the Detroit River to Lake St. Clair. Lake whitefish had a similar migration and entered the Detroit River. Similarly, the extinct blue pike (blue sub–species of walleye) formerly migrated between basins. The smelt and alewife, which replaced lake herring, do not exhibit migratory behaviour. In 2000, the movement of walleye was similar to that of blue pike. Whitefish have maintained their migratory pattern as they started to recover in the late 1980s and earlier 1990s. An index of ecosystem integration represented by fish migration is assessed to be mixed and improving.

Pressures on the System

Environmental conditions in the Lake Erie ecosystem continue to improve, but many pressures continue to challenge the physical integrity of the system. The Lake Erie ecosystem continues to be impaired by stressors caused by:

- introduction of non–native species;
- urban sprawl, development, and associated habitat destruction and loss;
- shoreline development and alterations;
- agricultural and industrial practices within the basin;
- atmospheric contaminant deposition from outside the basin; and
- global climate change.

There is an ongoing threat from new non–native species. Established invasive species have irreversibly altered the ecology of the Lake Erie ecosystem resulting in changes in all levels of the system. Lake Erie ranks second to Lake Ontario (31 sites) of all Great Lakes for the number of first records of aquatic invasive species. There have been 22 sites in the open waters of Lake Erie where non–native species were first reported (Corkum and Grigorovich 2003). Lake Erie proper has 34 non–native invasive fish species and new species are likely to enter the lake from the Mississippi drainage basin and from adjacent lakes.

Additional invasive species, including European ruffe and Asian carp, pose potential threats to Lake Erie. European ruffe are present in the upper Great Lakes and Asian carp are on the verge of entering Lake Michigan via the Chicago Sanitary and Shipping Canal. Impacts to the physical integrity of the ecosystem have reduced the resiliency of the ecosystem to invasive species introductions. Moreover, the threat from non–native species continue to exist from ballast water, intentional introductions through aquaculture, live fish markets, sport fishing, pet trade, and bait fishes.

Land use change has altered the physical integrity of the system and has increased suspended solids, BOD and sediment loadings to coastal wetlands, estuaries, and many nearshore areas resulting in increased turbidity, decreased dissolved oxygen and destruction of submerged aquatic vegetation. These conditions, in turn, have depressed zooplankton and benthic invertebrate production, particularly in nearshore areas. The result is reduced energy available for many forage and larval fishes at nearshore locations, especially estuaries that were formerly extremely important nursery zones for high value fish species.

Healthy wetlands are a valuable and intensively utilized fish habitat in the Great Lakes. Hardening of natural habitat has resulted in the loss of access (connectivity) to coastal wetlands for wetland species (40% of the Lake Erie fish community) and loss of historically significant production to the littoral zone and open lake. Direct and irreversible loss of coastal wetland and estuarine habitat and degradation of remaining wetlands by infilling, dredging, diking, tributary loadings, and other physical, chemical, and biological perturbations is likely one of several major factors responsible for altering the Lake Erie food web and fish community structure.

Regional climate change models (Canadian Centre for Climate Modeling CCGM1 and UKMO/Hadley Centre HADCM2) project a 1 to 2 m (3.3 to 6.6 ft) decline in long–term annual water levels in the Great Lakes over the next 70 years (Mortsch and Quinn 1996; Lee *et al*. 1996, Lofgren *et al*. 2002). Recent work by Wuebbles and Hayhoe (2003) using the HADCM3 model projects higher temperature changes for the mid–western U.S. than those predicted by the CCGM1 and HADCM2 models. Fan and Fay (2004) used net basin supply models based on four climate–change scenarios to show that, as compared to the base case, the levels of Lake Erie would fall by 15 cm to 81 cm (5.9 to 32 inches). Lee *et al*. (1996) predicted that a reduction in long–term annual water levels in Lake Erie and Lake St. Clair by 1.5 m (4.9 ft) or more would significantly reduce the lakes' surface area, moving the shoreline lakeward less than 1 km (0.6 mi) to as much as 6 km (3.7 mi). Reductions in water levels will likely hydrologically isolate many high–quality wetland and estuarine areas that are currently protected or maintained by gov-

Lake Erie Statistics	
Elevation[a]	
feet	569
metres	173
Length	
miles	241
kilometres	388
Breadth	
miles	57
kilometres	92
Average Depth[a]	
feet	62
metres	19
Maximum Depth[a]	
feet	210
metres	64
Volume[a]	
cu.mi.	116
km^3	484
Water Area	
sq.mi.	9,910
km^2	25,700
Land Drainage Area[b]	
sq.mi.	30,140
km^2	78,000
Total Area	
sq.mi	40,050
km^2	103,700
Shoreline Length[c]	
miles	871
kilometres	1,402
Retention Time	
years	2.6
Population: USA (2000)[d]	10,636,648
Population: Canada (2001)	2,032,283
Totals	12,668,931
Outlet	Niagara River Welland Canal

[a] measured at low water datum
[b] Lake Erie includes the St. Clair – Detroit system
[c] including islands
[d] 2000 population census data were calculated based on the total population of each county, either completely or partially, located within the watershed.

Sources:
The Great Lakes: An Environmental Atlas and Resource Book

Statistics Canada, Environment Accounts and Statistics Division, Spatial Environmental Information System and Censuses of Population 2001.

U.S. Census Bureau: State and County QuickFacts. Data derived from Population Estimates, 2000 Census of Population and Housing, 1990 Census of Population and Housing

ernment agencies and/or non–governmental conservation organizations (Mortsch 1998). Moreover, reduced water levels will alter nearshore littoral and sub–littoral habitats, permanently altering benthic and fish community structure throughout the Great Lakes. The effects of lower water levels will also fundamentally affect seasonal timing and connectivity, food web dynamics, and the distribution and diversity of biological communities in the basin (Casselman 2002, Kling *et al*. 2003).

Future and Emerging Management Issues
More effective methods to prevent the introduction of new invasive species into the basin and ways to prevent the spread of those that are already established are needed. Restoration of natural processes that restore the physical integrity of the Lake Erie ecosystem, including: protecting Lake Erie's water resources (diversions), restoration of natural flow regimes and connectivity in tributary and coastal systems, restoration of natural coastal processes, controlling urban sprawl and limiting habitat destruction and loss are important next steps. The need to anticipate long–term impacts of global change on water resources, habitat and the Lake Erie ecosystem is essential.

Acknowledgements/Sources of Information
Berkman, P.A., Haltuch, M.A., Tichich, E., Garton, D.W., Kennedy, G.W., Gannon, J.E., Mackey, S.D., Fuller, J.A., and Liebenthal, D.L. 1998. Zebra mussels invade Lake Erie muds. *Nature* 393:27-28.

Bertram, P., and Stadler-Salt, N. 2000. *Selection of indicators for Great Lakes Basin Ecosystem Health: Version 4*. http://www.epa.gov/glnpo/solec/solec_2000/Selection_of_Indicators_Version_4_(FULL).pdf, last accessed June 8, 2005.

Bolsenga, S.J., and Herdendorf, C.E. (eds.). 1993. *Lake Erie and Lake St. Clair Handbook*. Wayne State University Press, Detroit, Michigan.

Casselman, J.M. 2002. *Effects of temperature, global extremes, and climate change on year-class production of warm water, cool water, and coldwater fishes in the Great Lakes basin*. American Fisheries Society Symposium 32, pp. 39–60.

Charlton, M.N., and Milne, J.E. 2004. *Review of thirty years of change in Lake Erie water quality*. National Water Research Institute (NWRI) Contribution No. 04-167, Burlington, ON, Canada.

Christie, G.C., and Regier, H.A. 1988. Measures of optimal thermal habitat and their relationship to yields for four commercial fish species. *Can. J. Fish. Aquat. Sci.* 45:301–314.

Corkum, L.D., and Grigorovich, I.A. 2003. Update on non–native invasive species in Lake Erie. Draft 2004 LaMP Report, Chapter 11.2.

Cornelius, F.C., Muth, K.M., and Kenyon, R. 1995. Lake trout rehabilitation in Lake Erie: A case history. *J. Great Lakes Res.* 21(Supp. 1):65–82.

Dermott, R.M., and Kerec, D. 1997. Changes to the deepwater benthos of eastern Lake Erie since the invasion of *Dreissena*: 1979-1993. *Can. J. Fish. Aquat. Sci.* 54:922–930.

Dolan, D.M. 1993. Point source loading of phosphorus to Lake Erie. *J. Great Lakes Res.* 19:212–223.
Edwards, C.J., and Ryder, R.A. 1990. *Biological surrogates of mesotrophic ecosystem health in the Laurentian Great Lakes*. International Joint Commission (IJC), Windsor, Ontario.

Fan, Y., and Fay, D. 2004. *Upper Great Lakes water levels for four climate change scenarios*. Great Lakes–St. Lawrence Regulation Office, Meteorological Service of Canada, Environment Canada.

Fisher, J.P., Fitzsimmons, J.D., Combs, G.F., and Spitzbergen, J.M. 1996. Naturally occurring thiamine deficiency causing reproductive failure in Finger Lakes Atlantic Salmon and Great Lakes Lake Trout. *Trans. Am. Fish. Soc.* 125:167-178.

Fisheries and Oceans Canada. 2004. Canada's *Species at Risk Act (SARA)*. http://www.dfo-mpo.gc.ca/species-especes/home_e.asp, last accessed June 6, 2005.

Fitzsimmons, J.D., and Brown, S.B. 1998. Reduced egg thiamine levels in inland and Great Lakes lake trout and their relationship with diet. In *Early life stage mortality syndrome in fishes of the Great Lakes and Baltic Sea*, eds. G. McDonald, J.D. Fitzsimmons, and D.C. Honeyfield, pp. 160-171. Symposium 21, Bethesda, MD: American Fisheries Society.

Government of Canada, Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2002. http://www.cosewic.gc.ca/index.htm, last accessed June 6, 2005.

Halyk, L.C., and Davies, D.H. 1998. *Impairment of the beneficial use of Lake Erie fish habitat: draft summary*. Prepared for the Lake Erie LaMP Beneficial Use Sub-Committee, 61 pp.

Hartman, W.L. 1973. *Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie*. Great Lakes Fishery Commission Technical Report No. 22, 43 pp.

Hokanson, K.E.F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. *J. Fish. Res. Board Can.* 34:1524-1550.

International Joint Commission (IJC). 1993. *Levels reference study–Great Lakes–St. Lawrence River basin. Annex 2: Land Use and Management*. Report submitted to the Levels Reference Study Board, Phase II, IJC Levels Reference Study, 302 pp. plus appendices.

Johannsson, O.E., Dermott, R., Graham, D.M., Dahl, J.A., Millard, E.S., Myles, D.D., and LeBlanc, J. 2000. Benthic and Pelagic secondary production in Lake Erie after the invasion of *Dreissena* spp. with implications for fish production. *J. Great Lakes Res.* 26(1):31–54.

Kling, G.W., Hayhoe, K., Johnson, L.B., Magnuson, J.J., Polasky, S., Robinson, S.K., Shuter, B.J., Wander, M.M., Wuebbles, D.J., Zak, D.R., Lindroth, R.L., Moser, S.C., and Wilson, M.L. 2003. *Confronting climate change in the Great Lakes region: impacts on our communities and ecosystems*. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C., 105 p.

Lam, D.C.L., Schertzer, W.M., and Fraser, A.S. 1987. A post-audit analysis of the NWRI nine–box water quality model for Lake Erie. *J. Great Lakes Res.* 13:782–800.

Lam, D.C.L., Schertzer, W.M., and McCrimmon, R.C. 2002. *Modelling changes in phosphorus and dissolved oxygen pre– and post–zebra mussel arrival in Lake Erie*. National Water Research Institute (NWRI) Contribution No. 02–198, Environment Canada, Burlington, ON, Canada.

Lee, D.H., Moulton, R., and Hibner, D.A. 1996. *Climate change impacts on Western Lake Erie, Detroit River, and Lake St. Clair water levels*. Great Lakes–St. Lawrence Basin Project, Environment Canada and National Oceanic and Atmospheric Administration (NOAA), Great Lakes Environmental Research Laboratory (GLERL) Contribution #985, 44 p.

Lofgren, B.M., Quinn, F.H., Clites, A.H., Assel, R.A., Eberhardt, A.J., and Luukkonen, C.L. 2002. Evaluation of potential impacts on Great Lakes Water Resources based on climate scenarios of two GCMs: *J. Great Lakes Res.* 28(4):537–554.

Ludsin, S.A., Kershner, M.W., Blocksom, K.A., Stein, R.A., and Knight, R.L. 2001. Life after death in Lake Erie: nutrient controls drive fish species richness, rehabilitation. *Ecol. Appl.* 11:731–746.

Makarewicz, J.C., and Bertram, P. 1993. Evidence for the restoration of the Lake Erie ecosystem. *BioScience* 41:216–223.

Markham, J. and 12 Co-authors. 2004. *Report of the Coldwater Task Group to the Standing Technical Committee*. GLFC Lake Erie Committee, 100 pp.

Maynard, L., and Wilcox, D. 1996. *Coastal Wetlands*. State of the Great Lakes Ecosystem Conference (SOLEC) Working Paper. Mortsch, L.D. 1998. Assessing the impact of climate change on the Great Lakes shoreline wetlands. *Climate Change* 40:391–416.

Mortsch, L.D., and Quinn, F.H. 1996. Climate change scenarios for Great Lakes basin ecosystem studies. *Limnology and Oceanography* 401:903–911.

National Geophysical Data Center, National Oceanic and Atmospheric Administration (NOAA) Satellite and Information Service. 1998. www.ngdc.noaa.gov, last accessed June 6, 2005.

National Geophysical Data Center. 1998. Bathymetry of Lake Erie and Lake Saint Clair. In *World Data Center for Marine Geology and Geophysics report #MGG–13*, eds. L.A. Taylor, P. Vincent, and J.S. Warren. National Geophysical Data Center, Boulder, CO.

National Geophysical Data Center. 1998. *Bathymetry of Lake Erie and Lake St. Clair*. National Geophysical Data Center, Boulder, CO.

Ohio Department of Natural Resources (ODNR)–Division of Geological Survey. 2004. *Ohio Lake Erie Shore Structure Inventory*. Personal Communication.

Ontario Ministry of Natural Resources (OMNR). 2001. *Lake Erie fisheries report 2000,* 75 pp.

Richards, R.P., and Baker, D.B. 1998. Twenty Years of Change: The Lake Erie Agricultural Systems for Environmental Quality (LEASEQ) Project. In *Proceedings: national watershed water quality project symposium*, pp. 223-229. EPA/625/R-97/008.

Ryan, P.A., Knight, R., MacGregor, R., Towns, G., Hoopes, R., and Culligan, W. 2003. *Fish–community goals and objectives for Lake Erie*. Great Lakes Fishery Commission Special Publication 03–02, 56 pp.

Ryan, P.A., Witzel, L.D., Paine, J., Freeman, M., Hardy, M., Scholten, S., Sztramko, L., and MacGregor, R. 1999. Recent trends in fish populations in eastern Lake Erie in relation to changing lake trophic state and food web. In *State of Lake Erie (SOLE)–Past, Present and Future*, eds. M. Munawar, T. Edsall and I.F. Munawar, pp. 241-289. Ecovision World Monograph Series. Leiden, Netherlands: Backhus Publisher.

Ryder, R.A., and Edwards, C.J. (eds.). 1985. *A conceptual approach for the application of biological indicators of ecosystem quality in the Great Lakes basin*. Great Lakes Science Advisory Board, International Joint Commission, Windsor, Ontario, and Great Lakes Fishery Commission, Ann Arbor, Michigan.

Scott, W.B., and Crossman, E.J. 1973. Freshwater fishes of Canada. *Fish. Res. Bd. Can.* Bulletin 184, Ottawa.

Snell, E.A. 1987. *Wetland distribution and conversion in southern Ontario*. Canada Land Use Monitoring Program, Working Paper No. 48, Inland Lands and Waters, Directorate. Environment Canada.

SOLEC 2004 Presentations, Toronto, Ontario. 2004. *Lake Erie.* http://www.epa.gov/solec/solec_2004/presentations/index.html, last accessed June 6, 2005.

Stepien, C.A. 1995. Population genetic divergence and geographic patterns from DNA sequences: Examples from marine and freshwater fishes. In *Evolution and the aquatic ecosystem: defining unique units in population conservation*, ed. J. Nielsen, pp. 263-287. Bethesda, MD: American Fisheries Society Special Publication 17.

Todd, T.N., and Haas, R.C. 1993. Genetic and tagging evidence for movement of walleyes between Lake Erie and Lake St. Clair. *J. Great Lakes Res.* 19:445–452.

U.S. Fish and Wildlife Service. 2005. *The Endangered Species Program: FWS habitat conservation plan-land acquisition grant protects 1,800 acres of habitat in northwest Montana.* http://endangered.fws.gov, accessed June 6, 2005.

Wuebbles, D.J., and Hayhoe, K. 2004. Climate change projections for the United States Midwest. *Mitigation and Adaptation Strategies for Global Change* 9:335-363.

3.4 St. Clair–Detroit River Ecosystem –"The Corridor"

Assessment: The status of the St. Clair–Detroit River ecosystem is *mixed.*

Stressors to natural ecosystem persist, including the impacts of land use, shoreline alteration, nutrients and chemical contamination, and exotic invasive species. Contaminant levels in water and sediment continue to decrease, and habitat protection activities have increased.

Summary of the Status of the St. Clair–Detroit River Ecosystem

The St. Clair River, Lake St. Clair and Detroit River together serve as a corridor connecting Lake Huron and Lake Erie and serve as a major shipping channel linking the Upper and Lower Great Lakes. As a result of this shipping link, the region has developed into one of the most highly industrialized and environmentally altered areas in the Great Lakes basin. The cities of Port Huron and Detroit, Michigan and Sarnia and Windsor, Ontario are significant petrochemical and manufacturing centres within North America. There are four Areas of Concern in the St. Clair–Detroit River ecosystem (Figure 1).

Figure 1. St. Clair River-Lake St. Clair-Detroit River Ecosystem.
Source: Environment Canada

Beginning at Lake Huron, the St. Clair River flows approximately 64 km (40 mi) dropping 1.5 m (5 ft) through a predominately straight channel in a southerly direction before entering Lake St. Clair. Flowing through mostly urbanized areas, its banks are hardened with structures such as riprap and retaining walls with a few narrow beaches and vegetated bluffs.

The rapid deceleration of the flow from the St. Clair River as it enters the wide shallow Lake St. Clair allowed suspended sediment loads held in the river to settle out and over the millennium has formed the St. Clair Delta, one of the largest freshwater deltas in the world. The delta has a complex shoreline with many channels and shallow bays, providing some of the most significant fish and wildlife habitat in the Great Lakes. The opening of the Channel Cutoff in 1962, to improve commercial shipping, forever decreased the flow in the North Channel and the proportion of river water entering the lake through Anchor Bay. This opening has forever altered the hydrology and habitat availability of Anchor Bay.

Lake St. Clair has an area of 1,115 km^2 (430 mi^2) with a shoreline length of 272 km (169 mi) plus the delta shoreline. Its average depth is only 3.7 m (12 ft) with a maximum natural depth of 6.4 m (21 ft). A commercial navigation channel, running through the lake from the St. Clair River to the Detroit River, is 18 m (59 ft) wide and 8.3 m (27.2 ft) deep, making it the deepest point in the lake. The retention time for water in the lake ranges from four days for water from the Middle Channel to 30 days for water from the Thames River. Due to the shallow nature of the lake, it never thermally stratifies and oxygen levels throughout the water column are close to saturation. These characteristics provide the structure necessary to support large beds of emergent and submergent aquatic vegetation, diverse habitats, and significant fish and wildlife populations. They also make the lake vulnerable to annual and seasonal changes in water levels, weather, wake disturbance and contaminants.

Lake St. Clair is generally divided into two separate water masses (northwestern and southeastern). Water quality measurements indicate that these water masses only mix occasionally. The southeastern water mass is eutrophic and supports a diversity of nearshore and wetland habitats. The northwestern water mass is oligotrophic, and supports generally cooler, clearer water with less submergent vegetation (Figure 2).

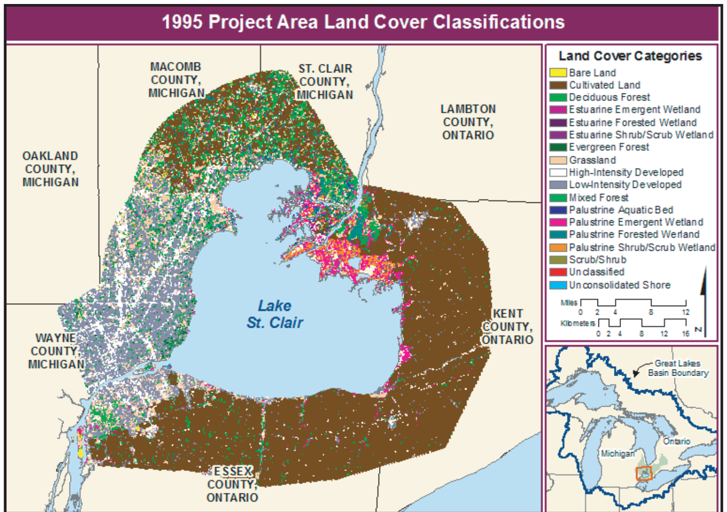

Figure 2. Lake St. Clair land cover classifications.
Source: Great Lakes Commission, 2004

Lake St. Clair has been affected by many invasive species that have and continue to alter the lake's physical and ecological integrity. For example, zebra mussels (*Driessena polymorpha*) first invaded the lake in 1988. Prior to their colonization (1976–1988) water transparency in the lake ranged from 0.9–1.9 m (3–6.25 ft) in Ontario waters. Post colonization (1989–1993) water transparency ranged from 1.2–4.0 m (4–13 ft). Their introduction has resulted in dramatic ecological changes to the lake including: decreased preferred habitat for walleye, a collapse of the native mussel population in the open lake, increased submergent aquatic vegetation, and an overall decrease in lake productivity.

Lake St. Clair drains into the Detroit River, running approximately 51 km (32 mi) and falling 0.9 m (3 ft) before discharging into Lake Erie. The river varies in depth from 1 m to 15 m (3–50 ft). There are twelve islands in the river. The river can be divided into two reaches, upper and lower, each with different hydraulic characteristics. The upper reach can be generalized as a narrow, deep channel with a steep shoreline that extends from Lake St. Clair to Fighting Island (downstream approximately 21 km or 13 mi) with a fall of only 0.3 m (1 ft). The lower reach by contrast is a wide, shallow channel with ten small islands. The river falls 0.5 m (1.5 ft) between Fighting Island and Bois Blanc Island, leaving a fall of less that 0.2 m (0.5 ft) for the remainder of the river. Extensive rock excavation and dredging was required to create the 5 navigational channels through the lower reach, forever altering the bottom structure of the river.

Flowing through the cities of Detroit, Michigan and Windsor, Ontario the Detroit River shorelines are densely industrialized and highly urbanized. This development altered significant amounts of shoreline, necessitated dredging, and caused watershed alterations that have resulted in very little natural habitat remaining in the Detroit River or its watershed.

Tributaries and sewers drain approximately 2,097 km^2 (807 mi^2) directly into the Detroit River. These inputs drain large industrial and urban areas and often contain elevated levels of sediment, nutrients, bacteria, metals, and chemicals. Large impermeable surfaces in the watershed often mean increased risks of local flooding; which further alters the natural watershed hydrology and contributes even more contaminates to the Detroit River.

These contaminants can bioaccumulate through the food chain impacting the health of fish and wildlife communities, resulting in consumption restrictions. Within the St. Clair Detroit River ecosystem monitoring by government agencies shows concentrations of mercury, PCBs and several pesticides in water and sediment are declining, while phosphorus and bacterial levels show no declines. Large areas of elevated contaminant concentrations can be found in the St. Clair River, Rouge River and the Trenton

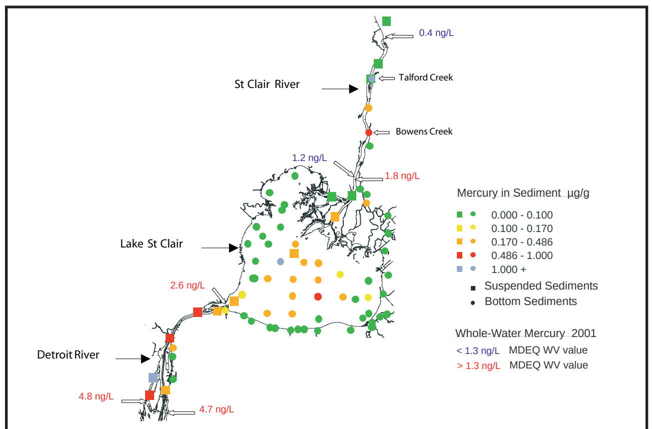

Figure 3. Mercury in sediment from the St. Clair-Detroit River ecosystem.
Source: Environment Canada

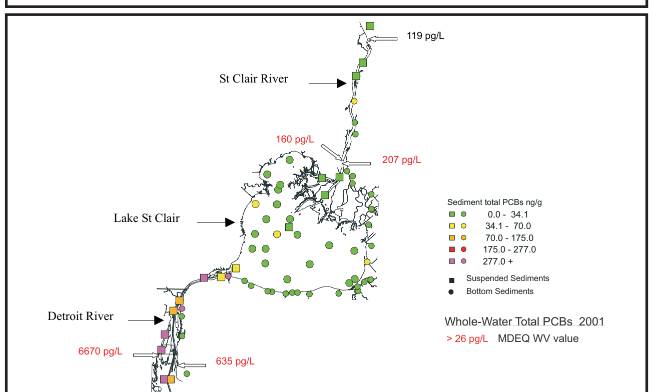

Figure 4. Total PCBs in the St. Clair-Detroit River ecosystem.
Source: Environment Canada

Channel, Detroit River (Figures 3 and 4). In some locations monitoring data are showing contaminant concentrations exceeding the Probable Effect Limits in recently deposited sediment, indicating that contaminated discharges are still occurring.

Pressures on the System

Environmental improvements within the St. Clair–Detroit River ecosystem are slowly occurring which indicates that the condition of the system is "mixed". For example, the corridor has some valuable fisheries, e.g. walleye, smallmouth, musky, although; it continues to have depressed fish stocks, e.g. sturgeon, herring, whitefish. Due to the complexity and diverse ecological variations throughout the St. Clair–Detroit River system, the status of the system in the near future will continue to be "mixed".

However, exotic invasive species, contaminants, hardened shorelines, loss of habitat and land use alterations continue to challenge the physical integrity of the system and these changes to the system often occur rapidly and more often than not, permanently.

There is an ongoing threat from new exotic invasive species. Established invasive exotic species have irreversibly altered the ecology of the St. Clair–Detroit River ecosystem resulting in changes at all levels of the ecosystem.

Changes to air temperatures, water levels, significant weather events and ice cover duration and thickness as a result of climate change, may have extensive and dramatic effects to this shallow, productive and fast flowing St. Clair–Detroit River system. These effects are of particular concern for littoral zones on the eastern and northern Lake St. Clair shorelines that are influenced by prevailing southwest winds. If water levels were to drop below a certain threshold, wave energy would be dissipated at an offshore bar and, in turn, may cause significant changes to the water transparency and sediment re-suspension in the littoral zone. Models predict significant shoreline and lake bed exposure, loss of critical open water and wetland habitats, increased requirements for dredging of marinas and the navigational channel, etc.

Historical and current discharges from industrial, urban, rural and agricultural land use affect the health and vitality of fish and wildlife populations and result in consumption restrictions, drinking water closures and beach closures.

Dredging and shoreline hardening to facilitate shipping or recreational boating and to protect against flooding including diking associated with residential areas, cottages, marinas and agriculture has significantly altered the hydrology of the St. Clair –Detroit River system. The altered hydrology changes the movement of sediments within the system, and can irreversibly change the location, extent, and diversity of habitats.

Future and Emerging Management Issues

The implementation of activities to eliminate chemical inputs, manage sediment and nutrient inputs, reduce the effects of exotic invasive species, prevent the introduction of new exotic species and manage for a more natural hydrology will improve the quality and quantity of habitats in the St. Clair–Detroit River system.

Lake St. Clair Statistics	
Elevation	
feet	569
metres	173
Length	
miles	26
kilometres	42
Mean Breadth	
miles	24
kilometres	39
Mean Depth	
feet	11
metres	3.4
Mean Annual Discharge[a]	
$ft.^3/s$	183,000
m^3/s	5182
Maximum Depth (natural)	
feet	21
metres	6.5
Land Drainage Area[b]	
sq.mi.	6,100
km^2	15,799
Water Surface Area[c]	
sq.mi	400
km^2	1036
Shoreline Length	
miles	62
kilometres	100

[a] Inflow into Lake St. Clair
[b] Land areas include the total drainage area to the outlet of the upstream lake
[c] Water Surface Area does not include area of connecting channels

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Source:
Lake St. Clair: Its Current State and Future Prospects, Lake St. Clair Network, United States Geological Survey

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Canadian Lake St. Clair Watershed Coordination Council. In press. *The Lake St. Clair Canadian Watershed Technical Report: An examination of current conditions*.

Michigan Department of Natural Resources and Ontario Ministry of the Environment. 1991. *Stage 1 Remedial Action Plan for the Detroit River Area of Concern*.

North–South Environmental Inc. 2003. In press. *2003 St. Clair River RAP Progress Report*. Volume 1–Synthesis Report.

SOLEC 2004 Presentations, Toronto, Ontario. 2004. *St. Clair: Upper Great Lakes Connecting Channels.* http:www.epa.gov/solec/solec_2004/presentations/index.html, last accessed June 7, 2005.

U.S. Army Corps of Engineers. In press. *St. Clair River–Lake St. Clair Binational Comprehensive Management Plan*.

3.5 Lake Huron

Assessment: The state of the Lake Huron ecosystem is *mixed and improving.*

While contaminant levels are low compared to the other Great Lakes and much of the main basin, Saginaw Bay, Georgian Bay and the North Channel still support extensive high quality coastal habitat, there are still issues regarding fish consumption restrictions, ecosystem change and the effects of non–native species as well as loss of fish and wildlife habitat. Shoreline development pressures, bacteria and nutrient problems, botulism outbreaks and concerns over water levels persist. Two AOCs have been delisted, one area has been recognized as an area in recovery and remediation efforts continue in the Saginaw Bay AOC. Fish and wildlife contaminant levels have substantially improved since the 1970s and populations of most fish–eating birds have recovered. While markedly different from historical fish communities, fish management efforts have resulted in a much improved fish community compared to 30 to 40 years ago.

Summary of the Status of the Lake Huron Ecosystem
The diverse shoreline of Lake Huron is the longest of the Great Lakes, its length extended by the shores of its over 30,000 islands. Rocky shores associated with the Precambrian Shield cover the northern and eastern shores, limestone dominates the shores of Manitoulin Island and the northern shore of the Bruce Peninsula, and glacial deposits of sand, gravel and till predominate in the western, southern and southeastern portions of the shore. Shoreline and inshore habitats are correspondingly diverse.

The Lake Huron basin is heavily forested in the northern portion and then becomes increasingly agricultural in the south with its urbanized areas in Saginaw Bay and along the southernmost portion of the lake. Much of southern part of the Huron basin is

Figure 1. Lake Huron drainage basin.
Source: Environment Canada

devoted to intensive cultivated field crops and, beef and dairy farms, particularly in the "thumb" area of Michigan, along the Bruce Peninsula, and the southeast shore of the main basin. Mining of limestone, nickel, uranium, copper, platinum and gold has been an important activity in the northern portion of the Lake Huron basin.

The Lake Huron watershed is home to about 2.5 million people. Both the U.S. and Canadian sides of Lake Huron have relatively low human population densities. As a result, Lake Huron retains much of its historic fish and wildlife habitat. Saginaw Bay, Georgian Bay, and the North Channel still support some of the most extensive, high quality coastal habitat in the Great Lakes.

Lake Huron is the third largest freshwater lake in the world in terms of area, and the sixth largest in volume and boasts the largest island (Manitoulin) of any freshwater lake on Earth. The retention time for water in Lake Huron is 22 years, and the average depth is 59 metres (195 feet). This long retention time and large surface area have resulted in the build up of persistent substances that bioaccumulate in fish and wildlife.

Four Areas of Concern (AOCs) were identified in the Lake Huron basin. Within the basin two AOCs, Saginaw Bay, Michigan, and Spanish Harbour, Ontario remain (Figure 1). The causes of impairment within the AOCs are being addressed, and habitat, fish and wildlife populations and environmental quality are recovering. Canada and Ontario have recognized Spanish Harbour as an "Area in Recovery" where all remedial actions have been implemented. The environment will take some time to respond to the work completed in Spanish Harbour and for the goals to be achieved. Severn Sound, Ontario was delisted as an AOC in 2003 and the Collingwood Harbour AOC, also in Ontario, was delisted in 1994.

From the late 1970s to the early 1990s, concentrations of persistent, bioaccumulative substances such as PCB, DDT, dieldrin, dioxins and furans declined significantly in Lake Huron lake trout. However, while concentrations of DDT continued to decline up until 1995, PCB concentrations have not declined significantly since the mid 1980s. As with other trends, concentrations decreased significantly in the late 1970s but have remained relatively stable since (Figure 2).

In the early 1970s, fish–eating birds (eagles, gulls, cormorants, etc.) on Lake Huron suffered widespread contaminant–induced reproductive failure, declining populations and eggshell thinning. With reductions in loadings of persistent toxic contaminants, such as PCBs, most fish–eating bird populations have recovered; numbers of herring gulls, Caspian terns, black–crowned night–herons and double–crested cormorants have increased significantly. However, some contaminant–associated problems, e.g. birth defects and reproductive failure, continue to occur in a small percentage of the populations in local areas.

The lake ecosystem has undergone many changes. Among the most significant change to the fish community has been the invasion of rainbow smelt in the 1920s, and alewife and sea lamprey in the 1930s. Sea lamprey predation and overfishing led to the collapse of lake trout by the 1950s (although two remnant stocks barely survived). With no predators to control alewife and smelt populations their numbers exploded and nuisance die–offs of alewife commonly littered beaches during the 1960s. The turnaround came with sea lamprey control in the 1960s which allowed the survival of stocked Pacific salmon, lake trout and other predators. Restocking controlled both smelt and alewife populations, prevented nuisance alewife die–offs and resulted in exceptionally good fishing.

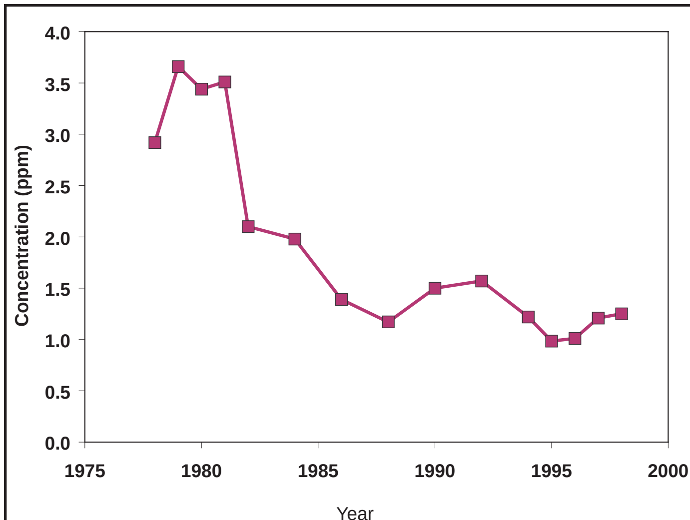

Figure 2. Lake Huron PCB concentrations in whole lake trout. Source: DeVault *et al.*1996. U.S. Environmental Protection Agency, unpublished data.

The original Lake Huron ecosystem had lake trout as the main predator together with burbot in the deeper waters, and walleye the main nearshore area predator. The historic prey base was dominated by lake herring (or cisco) and a number of other species of deepwater ciscos, with sculpins, lake whitefish, and round whitefish contributing to a lesser extent. The historic Lake Huron offshore ecosystem had fewer predators and many more prey fish species (Figure 3). The current ecosystem has many more predators and both predators and prey are dominated by introduced species. Many of the original deepwater cisco species in Lake Huron are extirpated.

Today chinook salmon is the dominant consumer in the lake,

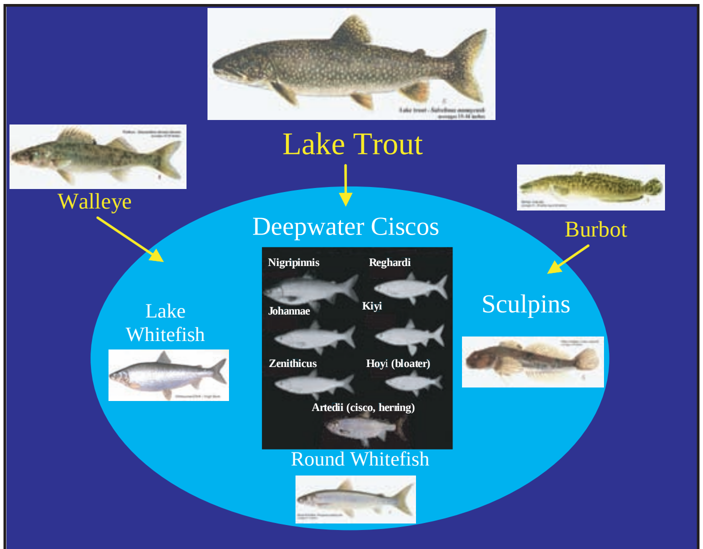

Figure 3. The historic Lake Huron offshore ecosystem. This system had fewer predators and many more prey fish species. Source: Minnesota Department of Natural Resources, New York Department of Environmental Conservation, Ontario

feeding mainly on non–native forage (alewife are their main prey with smelt being second) and lake trout are still a significant consumer due to continued stocking in the lake. The abundance of both alewife and smelt can fluctuate significantly between years which can influence growth rates and survival of

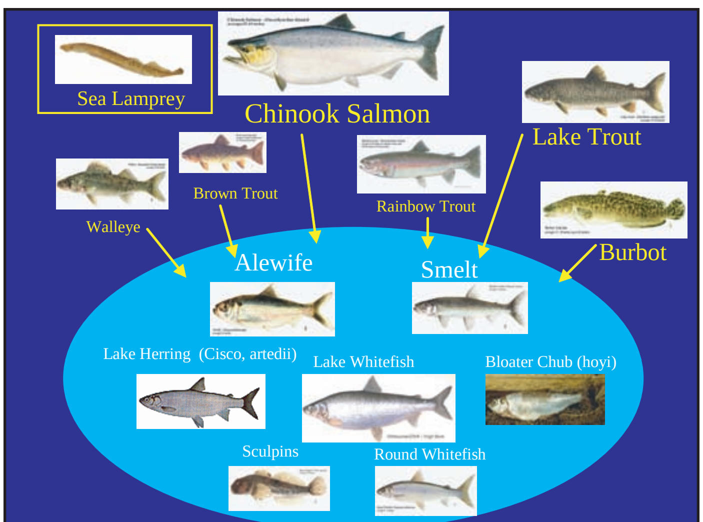

Figure 4. The current Lake Huron offshore ecosystem. The current system has many more predators and both predators and prey are dominated by introduced species. Many of the original deepwater cisco species in Lake Huron are extinct. Source: Minnesota Department of Natural Resources, New York Department of Environmental Conservation, Ontario Ministry of Natural Resources, and Wisconsin Department of Natural Resources

predators (Figure 4). Six sites of natural reproduction of lake trout have been documented on Lake Huron and one has been deemed rehabilitated. Despite this level of success, much work is needed to rehabilitate lake trout numbers to even a small portion of their former abundance across the lake.

The current lake ecosystem may not be as productive as in the past since non–native prey species are not as efficient in utilizing the primary and secondary production of the lake as were historic species, such as the diversity of ciscos that once inhabited the lake. The introduction of non–native species such as zebra and quagga mussels and the spiny water flea may also divert much of the primary and secondary production of the lake to different pathways, making it unavailable to top predators.

Major changes are occurring rapidly on Lake Huron. As of 2004 the fish community is seeing a drastic decline in alewife abundance, resulting in large declines in Chinook salmon growth rates. At the same time, there is evidence of very large levels of Chinook salmon natural reproduction, continued *Diporeia* declines in the main basin and Georgian Bay, huge 2003 and 2004 year classes of walleye and yellow perch and early indications of bloater chub and lake herring recovery. These recent changes do not provide a clear indication of the future state of the Lake Huron fish community. More information will be reported for SOLEC 2006.

Pressures on the System

Continuing sources of contaminants are primarily from airborne deposition, industrial and municipal discharges, land runoff and sediment contaminated by historic discharges. Contaminants enter Lake Huron through a variety of pathways including direct discharges, atmospheric deposition and tributary discharge. Pesticides such as DDT, toxaphene, mirex, chlordane and aldrin/dieldrin have been banned from use in the U.S. and Canada; however, they are still cycling within the environment through run–off, sediment resuspension and long range atmospheric transport. Lake Huron has relatively few local contaminant point sources but has a large surface area which makes it vulnerable to atmospheric deposition of contaminants. Pollutant loadings to Lake Huron from water sources are lowest of all the Great Lakes but air sources are the highest.

Wildlife information has indicated that PCBs, chlordane, dioxins and DDT are a concern in the Lake Huron basin although, with the exception of Saginaw Bay (PCBs, dioxin), concentrations are low compared to the other Great Lakes. Concentrations have declined significantly since the early 1970s but still remain at levels associated with deformities and reproductive effects in several local watersheds in Michigan, especially Saginaw Bay. Data collected in Ontario's wildlife species were generally not at levels of concern although sporadic elevated measurements support the need for continued ongoing monitoring.

Lake Huron has been dramatically and forever changed by the invasion of non–native species, which have decimated native fish populations and in some cases permanently impacted fish communities. Invasive species are defined as species that do not originate in the Lake Huron ecosystem and have been introduced either intentionally or accidentally. Invasive species threaten the diversity and abundance of native species and the ecological stability of infested waters. Their disruption has altered food webs, nutrient dynamics, reproduction, sustainability and biodiversity. Invasive species have few natural enemies such as pathogens, parasites and predators. Without co–evolved parasites and predators, they out–compete and even displace native populations. Not only do invasive species compete with native species for food and habitat, they may also increase the cycling of persistent bioaccumulative chemicals in the food chain. For example, research has shown that zebra mussels and round gobies are contributing to the cycling and bioaccumulation of PCBs in the Great Lakes.

Many fish need to migrate between different habitats throughout their life histories. In the past, Lake Huron was connected to diverse array of stream and inland lake habitats. Historically, tributaries were important sources of cool, high quality water, and they served as spawning and nursery habitats for many species. Fish were excluded from many of these areas in the 1800s through the construction of mill dams and later through the establishment of hydroelectric facilities. Dams now fragment many streams where historical spawning occurred for adfluvial fish (fish that live in the open waters of the Great Lakes and use tributaries for spawning). Many important fisheries and spawning rapids are no longer accessible.

In recent years, outbreaks of Type E Botulism have left hundreds of fish and waterbirds dead on Ontario beaches of Lake Huron. In 1998 and 1999, the outbreak appeared to be concentrated at the south end of the lake between Goderich and Sarnia. In 2002 and 2003, outbreaks occurred in the Goderich to Port Elgin areas. The occurrences began in late summer and continued through the fall season until late November. There were also observations of decomposing algae collecting in embayments in the Kincardine area in the late summer. These events on Lake Huron are being studied along with similar events on Lakes Erie and Ontario to determine what conditions lead to these Type E Botulism outbreaks.

The watershed of Lake Huron along its southeast shore (Sauble Beach to Sarnia) is a draw for thousands of tourists and cottagers annually as it boasts some of the finest freshwater beaches in the world. High levels of nutrients and bacteria (*E. coli*) along the beaches and in the tributaries have led to numerous postings of beaches warning of unsafe conditions for swimming. These conditions have existed for many years yet have received heightened attention due to recent media coverage. Complaints from residents about algae have been less frequent, and are sporadic geographically and over time with some years being much worse than others. The relative contributions of sources of nutrients and bacteria have not been specifically quantified; however agricultural practices, municipal wastewater, septic systems and wildlife sources are all contributors.

Future and Emerging Management Issues

In comparison to the other Great Lakes, contaminant concentrations are relatively low in Lake Huron. Nevertheless, fish consumption advisories exist for the open lake and all Areas of Concern including Saginaw Bay and the Spanish River as well as the St. Marys River AOC which is upstream of Lake Huron.

The recent invasion of zebra and quagga mussels, round gobies, the spiny water flea, white perch and ruffe into Lake Huron heightens the uncertainty for expectations from the ecosystem. Recently, *Diporeia hoyi* (scud), a native invertebrate has declined significantly in abundance, especially in southern Lake Huron. There is a suspicion that the *Diporeia* decline may be related to the invasion of zebra mussels. *Diporeia* is a key diet item of lake whitefish and other desirable sport and commercial fish species.

Though residential land use comprises a small percentage of the total land use in the Lake Huron basin, much rural development has occurred along the shoreline. In the past 20 years, there has been increasing development pressure for cottages and year–round retirement properties. Undoubtedly, the next 20 years will bring more development pressures as urban populations grow and the retired population increases.

Recent advances in chemical detection techniques have revealed the presence of low concentrations of chemical contaminants that were previously not known to be present. Studies in other aquatic systems have detected a wide range of chemicals including personal care products (soaps and perfumes), human and veterinary drugs (antibiotics), natural and synthetic hormones, plasticizers, insecticides, fire retardants and caffeine. Concentrations of these chemicals almost never exceed standards set for drinking water, but some substances do not have established standards because it was not previously known that they were even present in the water. The primary concern with low–level contaminants is that they may serve as endocrine disrupters that affect growth, maturation and reproduction of aquatic organisms. The problem is so new that many basic questions remain unanswered.

Looking toward the future, 2007 has been tentatively identified for the comprehensive monitoring and analysis of the health of

Lake Huron. This year appears to work well for existing monitoring schedules, although much more work will be necessary to coordinate monitoring on this geographic scale.

Acknowledgments/Sources of Information
Janette Anderson, Environment Canada–Ontario Region
James Schardt, U.S. Environmental Protection Agency–Great Lakes National Program Office

Devault, D.S., R. Hesselberg, P.W. Rodgers and T.J. Fiest. 1996. Contaminant Trends in Lake Trout and Walleye from the Laurentian Great Lakes. J. Great Lakes. Res. 22(4):884–8895.

SOLEC 2004 Presentations, Toronto, Ontario. 2004. *Lake Huron.* http://www.epa.gov/solec/solec_2004/presentations/index.html, last accessed June 7, 2005.

U.S. Environmental Protection Agency (EPA). 2004. Lake *Huron Binational Partnership Action Plan*. http://www.epa.gov/greatlakes/lakehuron/, last accessed June 9, 2005.

Lake Huron Statistics	
Elevation[a]	
feet	577
metres	176
Length	
miles	206
kilometres	332
Breadth	
miles	183
kilometres	245
Average Depth[a]	
feet	195
metres	59
Maximum Depth[a]	
feet	750
metres	229
Volume[a]	
cu.mi.	850
km^3	3,540
Water Area	
sq.mi.	23,000
km^2	59,600
Land Drainage Area[b]	
sq.mi.	51,700
km^2	134,100
Total Area	
sq.mi	74,700
km^2	193,700
Shoreline Length[c]	
miles	3,827
kilometres	6,157
Retention Time	
years	22
Population: USA (2000)[d]	3,281,897
Population: Canada (2001)	1,333,513
Totals	4,615,410
Outlet	St. Clair River

[a] measured at low water datum
[b] land drainage area for Lake Huron includes St. Marys River
[c] including islands
[d] 2000 population census data were calculated based on the total population of each county, either completely or partially, located within the watershed.

Sources:
The Great Lakes: An Environmental Atlas and Resource Book

Statistics Canada, Environment Accounts and Statistics Division, Spatial Environmental Information System and Censuses of Population 2001.

U.S. Census Bureau: State and County QuickFacts. Data derived from Population Estimates, 2000 Census of Population and Housing, 1990 Census of Population and Housing

3.6 Lake Michigan

Assessment: The physical integrity of the Lake Michigan ecosystem is *mixed.*

"Lake Michigan is an outstanding natural resource of global significance, under stress and in need of special attention" (Lake Michigan LaMP 2000). Since the original 2000 assessment, there has been both positive and negative change in the Lake Michigan basin. Positive work includes sediment clean ups, the purchasing of large land parcels for preservation purposes, and the rebounding of terrestrial species. Some negative changes include continued pressure from invasive species on the aquatic food web and land development in the near coastal areas.

Background Summary

Lake Michigan is one of the most complex ecosystems of the Great Lakes due to its length of 307 miles (494 km). It varies from north woods forest to southern dune and swale environments. The largest collection of fresh water sand dunes in the world is a prominent feature, as are Lake Michigan's islands which are grouped into two northern archipelagoes of 19 Grand Traverse Islands and Beaver Islands. Many of the islands have suffered a loss of natural habitat due to development and are moderately degraded. Several of the Beaver Islands are part of the Michigan Islands National Wildlife Refuge providing 235 acres (95 ha) of habitat for migratory and colonial nesting birds and federally threatened plants like dwarf iris and Pitcher's thistle. There are three islands totalling 29 acres (12 ha) in the Green Bay National Wildlife Refuge that offers similar habitats. Underwater reefs in both the nearshore and offshore are thought to play an important role in Lake Michigan spawning.

Lake Michigan is the second largest Great Lake by volume and

Figure 1. Lake Michigan drainage basin.
Source: Environment Canada

contains over 20% of the Great Lakes' coastal wetlands which are responsible for the quantity and diversity of aquatic life seen in the lake. Protection and enhancement of these areas are key to the future sustainability of the coastal ecosystem.

Lake Michigan is uniquely positioned with a direct connection to the Mississippi River System through the Chicago Diversion, and as such, has become a transfer point for many non–native species which threaten the biological integrity of all the Great Lakes and the Mississippi River.

Lake Michigan has 33 8–digit hydrologic unit code (HUC) tributary watersheds, with all but three listed as impaired and 10 estuaries designated as Areas of Concern (Figure 1). Many Michigan and Wisconsin tributaries have been dammed in the past, but recent dam removals in southeastern Wisconsin have resulted in improved fish habitat, water quality and diversity of species including the appearance of the rare greater redhorse in the Milwaukee River.

Over 10 million people are dependent on Lake Michigan for high quality drinking water and recreation. Since the passing of the U.S. Beaches Environmental Assessment and Coastal Health (BEACH) Act in 2000, the four Lake Michigan states are on track for implementing these provisions with an average of 50% more monitoring using enhanced water quality standards. The results have led to increased advisories and the need for studies to determine contamination sources and management options.

Groundwater Flow

Groundwater beneath the Great Lakes has a different and changeable divide than the Great Lakes surface/watershed divide. In the Great Lakes basin, most shallow flow discharges to local streams; the Great Lakes watershed divide (i.e. the sub–continental divide) also serves as a groundwater divide for shallow flow. Most deep flow discharges are to regional sinks with the deep aquifer divide being distant from the surface watershed divide (Figure 2).

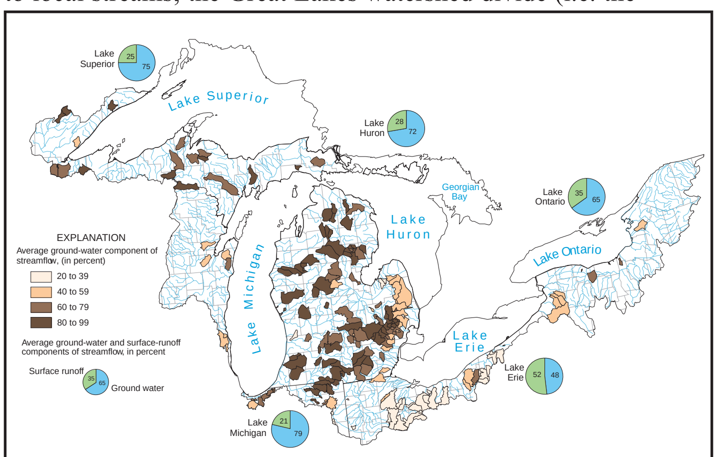

Figure 2. Average groundwater and surface runoff components of selected watersheds in the U.S. portion of the Great Lakes basin.
Source: Holtschlag and Nicholas, 1998

Groundwater divides move in response to pumping. Studies from the western Lake Michigan groundwater basin report that the 1950 pre–development divide and the year 2000 divide for the deep bedrock aquifer, show a pattern of movement. The western basin groundwater that once flowed east toward Lake Michigan is now intercepted by pumping and diverted west under the surface–water divide.

Groundwater, once used, can be discharged to surface water bodies in a different basin. Since the late 1940s, development on the Mississippi basin side of the sub–continental divide has reversed deep flow patterns between west of the divide and the Milwaukee area. The groundwater levels are low enough that Lake Michigan can migrate into the groundwater, a reversal of the normal flow (U.S. Geological Survey 1998).

Groundwater's Role in the Health of the Lake Michigan Ecosystem

The Great Lakes are in a topographically low setting that, under natural flow conditions, causes them to function as discharge areas or "sinks" for the groundwater–flow system. Most groundwater that discharges directly into the lakes is believed to take place near the shore (Grannemann and Weaver 1999). Of all the Great Lakes, Lake Michigan has the largest amount of direct groundwater discharge (2,700 ft^3/s or 76 m^3/s) because it has more sand and gravel aquifers near the shore than any of the other Great Lakes (Grannemann and Weaver, 1999). Although this is a relatively low inflow compared to the total stream flow into the lake from land areas (41,200 ft^3/s or 1167 m^3/s) (Croley and Hunter 1994), it is nearly equal to the amount of water diverted from Lake Michigan through the Chicago Ship and Sanitary Canal (Table 1) (Oberg and Schmidt 1994).

Lake	Overlake Precipitation (percent)	Surface-Runoff (percent)	Indirect groundwater discharge (percent)
Superior	56.3	11.0	32.7
Michigan	56.2	9.3	34.5
Huron	42.2	16.3	41.5
Erie	53.5	24.3	22.2
Ontario	34.8	22.8	42.4

Table 1. Basin water supply for the Great Lakes.
Source: U.S. Geological Survey, 1998. Water Supply Paper

Groundwater Provides Refuge for Aquatic Organisms

Groundwater discharge to streams may help provide important habitat for aquatic organisms, including fish. In addition, because groundwater temperatures are nearly constant throughout the year, stream reaches with relatively large amounts of groundwater discharge can provide refuge to organisms from heat in summer and from cold in winter. For example, some stream reaches in the region remain unfrozen even though air temperatures are well below 32 degrees Fahrenheit (0 degrees Celsius). Other possible benefits to the survival of aquatic organisms related to groundwater discharge to streams include increasing concentrations of dissolved oxygen, adding small amounts of nutrients that are essential to the health of organisms, providing cold pockets of water in summer, and maintaining stream flow during dry periods.

Lake Levels

Lake Michigan's water level was measured at 2 feet (61 cm) below the long–term average in 2001, having dropped more than 40 inches (102 cm) since 1997 when it was at near record highs. Levels increased for 2002, but were still below average. The decrease in precipitation over the last five years resulted in Lake Michigan being at its lowest point since 1966. Lake levels rose between the mid–1960s and the late 1990s.

The lower lake level has caused problems for the shipping and boating industry. Cargo ships were forced to lighten their loads, and many boat ramps became inaccessible. According to the U.S. Great Lakes Shipping Association, for every inch (2.5 cm) of water that Lake Michigan loses, a cargo ship must reduce its load by 90 to 115 metric tons, leading to losses of between $22,000 and $28,000 U.S. per trip.

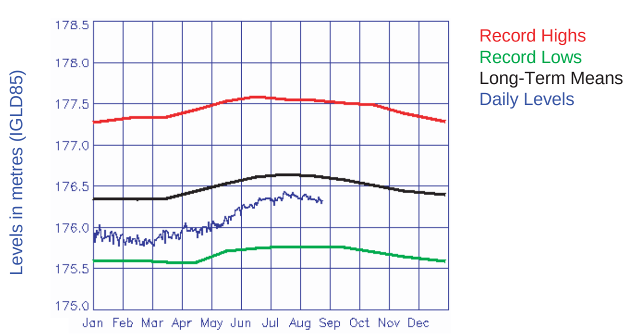

Figure 3. Lake Michigan-Huron water levels.
Source: Great Lakes Environmental Research Laboratory-National Oceanic and Atmospheric Administration

Early reports for 2004 indicated that the lake level was at an average depth due to increased rainfall early in the year. The lake measured one foot higher (30.5 cm) in the summer of 2004 than 2003 with the mean average of 579 feet or 176 metres. This fluctuation may be part of a 30–year cycle that deserves continued monitoring (Figure 3). (U.S. ACE, Detroit District)

Beaches

Lake Michigan contains the world's largest collection of fresh-water sand dunes and associated beaches, particularly along its eastern shore. Of a total of 3,100 acres (1,255 ha) along the coast, 1,200 acres (486 ha) are publicly owned and available for use, while another 1,200 acres (486 ha) are privately owned and have significant potential for public use. In addition to swimming advisories due to poor water quality, there has been a resurgence of the macro algae *Cladophora* along the coast. *Cladophora* blooms result in reduced water quality and beach use. Causes of this problem may be attributed to multiple factors, such as lower lake levels, increased water temperature, nearshore nutrients and zebra mussel activity (Great Lakes Water Institute, University of Wisconsin at Milwaukee).

Aquatic Food Web

The Lake Michigan aquatic food web is threatened due to invasive species competing for food and changing the physical environment (Figure 4). Zebra mussels have the ability to filter water allowing sunlight to penetrate to greater depths, possibly causing algae blooms. The invertebrate *Diporeia* is decreasing rapidly in Lake Michigan thus removing a foundation component of the food web (Figure 5). The yellow perch population remains low and zebra mussels, first introduced in 1989, have shown a decline in certain areas. Sea Lamprey populations have increased in abundance and are now higher than in Lakes Superior or Huron. Lake Trout are stocked and have not recovered to the point of natural reproduction in the lake.

Lake Sturgeon survive in the Great Lakes only in scattered remnants, even though large scale commercial fishing for them ended a century ago. There were remnant populations known to spawn in the waters of 8 tributaries with connections to Lake Michigan. In 2003, enhanced stocking was undertaken with the hopes that the stocked sturgeon would flourish, but not genetically impact the small remnant native population. There are currently 16 agencies and institutions involved with Lake Sturgeon monitoring and investigations are coordinated by the U.S. Fish and Wildlife Service Great Lakes Basin Ecosystem Team.

The most dramatic threat to Lake Michigan is from the Asian carp species which is working its way up the Illinois waterway system from the Mississippi River. The Asian carp was reported to have escaped from aquaculture ponds adjacent to the Mississippi River in the 1980s and the 1990s. An experimental electrical barrier is currently in place. Improvements to this barrier as well as an additional barrier are planned. This large carp species weighs up to 90 pounds (41 kg) and is considered a major threat to the Great Lakes food web.

Other Species

Land–based species are fairing better. The grey wolf is now listed as a recovered species and bald eagles have nested in the area of the Little Calumet River for the first time in 100 years.

Kirtland's warbler, piping plover, Hine's emerald dragonfly and the Karner blue butterfly all have recovery plans in place. An aggressive program to train whooping cranes to migrate and return to Wisconsin's wetlands (west of Lake Michigan) for future nesting is underway.

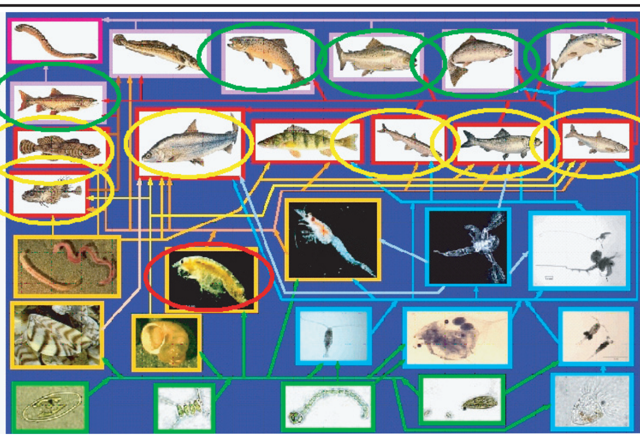

Figure 4. Lake Michigan foodweb. *Diporeia*, central in the diagram, was historically an important food for the fish on the second line of the figure (species in the red squares). *Diporeia* are the prey for the large predator fish like salmon and lake trout at the top of the chart and foodweb (species in the purple squares). Non-native species are competing with, and possibly replacing the *Diporeia* in the Lake Michigan ecosystem. The loss of *Diporeia* threatens the species that feed upon it and the whole foodweb.
Source: Mason, Krause and Ulanowicz, 2002

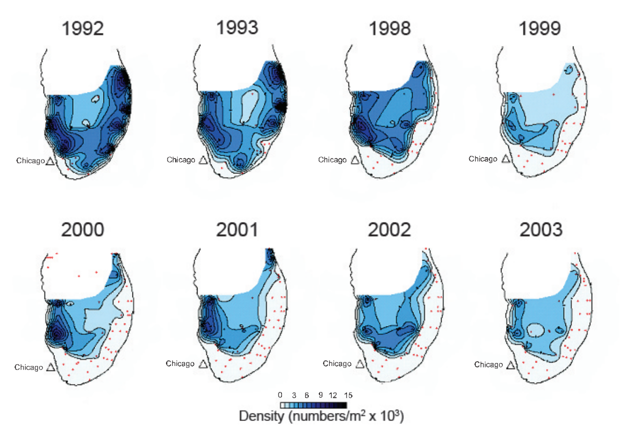

Figure 5. *Diporeia* density.
Source: Great Lakes Environmental Research Laboratory-National Oceanic and Atmospheric Administration

Natural Areas

The dune and swale systems of the eastern lakeshore are a dominant feature of Lake Michigan and provide unique habitat that foster biodiversity. While afforded some protection under law, this system faces extreme pressure as it is a sand product for industry. This area also has development pressures in the coastal communities.

Wetlands, which naturally help control runoff from urban areas by storing flood and surface water and slowly release and filter it, have been destroyed in the Lake Michigan basin states to a greater degree than elsewhere in the country. An estimated 21.9 million acres (8.9 million ha) of wetlands or 62.9% have been lost. An estimated 12.9 million acres (5.2 million ha) of wetlands remain in the four Lake Michigan states, equivalent to approximately 12.3% of the wetland area in the lower 48 states. While this percentage is for the U.S. states not just the Lake Michigan basin, it is indicative of the pressure on the wetland systems. Wetland status in the Lake Michigan basin is therefore mixed (Dahl 1990).

Forest status in the basin is good due to revisions to national forest plans (September 2003 U.S. Federal Register Notice) and the continued practice of sustainability forestry management by the Menominee Tribal Enterprises. The new forest plans address old growth management issues. The Menominee Reservation 235,000 acres (95,102 ha) of forest land represent 150 years of sustainable forest practice in the Wisconsin portion of the Lake Michigan basin.

Lakeplain system of prairies and savannas found in the southern part of the basin are two of the most imperiled ecological communities in North America. Alvars, open areas of thin soils over bedrock found in the northern basin, provide habitat for a number of rare plants and animals. Both of these systems are facing fragmentation and destruction due to land use development.

Pressures on the System

The 10 Areas of Concern in the Lake Michigan basin have contaminated sediment problems and either combined sewer overflows (CSO) and/or storm water problems. All 10 AOCs had some remedial sediment work completed with much more remediation still required. For most of the sediment sites and CSOs there are plans in place but implementation is often forecasted for the year 2020 or beyond. PCBs are the main contaminant in sediment and fish consumption advisories are in place around the lake thus keeping the assessment for fish communities in the Lake Michigan basin as mixed.

The urbanized land area in the United States has quadrupled since 1954. To compound the problem, populations in coastal areas, which contain some of the most sensitive ecosystems, have been increasing even faster than in the rest of the country. From 1982 to 1996, the population in the Chicago–Northwest Indiana area grew by 10.9% but consumed 44.2% of the land (Urban Roadway Congestion: Annual Report 1998). The

Northeastern Illinois Planning Commission's portion of the area is estimated to grow by 21% from 2000 to 2030. This growth pattern is similar to other growth areas around the lake and will further tax water infrastructure and resources.

USEPA's Office of Environmental Information states "the construction of impervious surfaces such as roads and rooftops leads to the degradation of water quality by increasing runoff volume, altering regular stream flow and watershed hydrology, reducing groundwater recharge, and increasing stream sedimentation and water acidity." A one acre (0.4 ha) parking lot produces a runoff volume 16 times as large as that produced by an undeveloped meadow. Many impervious construction materials have higher surface temperatures that may cause ambient air temperatures to rise. When combined with a decrease in natural vegetation, areas are subject to the "urban heat island" phenomenon, which may increase utility bills, cause health problems associated with heat stress, and accelerate the formation of harmful smog. Clearly the effect of urban development on our communities and environment is a cross–cutting issue.

Both the urban and agricultural uses of the land impact the lake. The Lake Michigan Mass Balance Study has modelled the pesticide atrazine in the basin and a draft report and models have determined the need for over a 50% annual reduction in loadings from agriculture lands and the air in order to keep this pesticide at a steady state in the lake. While nutrient levels are increasing in the nearshore areas due to urban runoff, these levels are not at concentrations of concern in the open lake.

Management Actions

For a lake the size and complexity of Lake Michigan, it is not surprising that there are some measures of improving conditions as well as measures of deteriorating conditions. As some issues approach resolution, other new issues are developing such as chemicals of emerging concern and new invasive species. Since the overall status of the lake involves the interactions of chemical, physical and biological changes, it is necessary to understand the interactions of how improvements in one of these categories will affect the other conditions in the lake.

There are many research and reporting needs required for Lake Michigan which include:

- determining the groundwater status, mapping and groundwater and surface water interactions;
- identifying sources of *Cladophora and E. Coli* including the interactions between physical and biological forces which affect the health of Lake Michigan beaches;
- tracking invasive species and their impact on the food web and natural areas;
- identifying protected natural areas, ground areas below flyways, unique features and wetlands and educating the public

Lake Michigan Statistics	
Elevation[a]	
feet	577
metres	176
Length	
miles	307
kilometres	494
Breadth	
miles	118
kilometres	190
Average Depth[a]	
feet	279
metres	85
Maximum Depth[a]	
feet	925
metres	282
Volume[a]	
cu.mi.	1,180
km^3	4,920
Water Area	
sq.mi.	22,300
km^2	57,800
Land Drainage Area	
sq.mi.	45,600
km^2	118,000
Total Area	
sq.mi	67,900
km^2	175,800
Shoreline Length[b]	
miles	1,638
kilometres	2,633
Retention Time	
years	99
Population: USA (2000)[c]	15,351,202
Totals	15,351,202
Outlet	Straits of Mackinac

[a] measured at low water datum
[b] including islands
[c] 2000 population census data were calculated based on the total population of each county, either completely or partially, located within the watershed.

Sources:
The Great Lakes: An Environmental Atlas and Resource Book

Statistics Canada, Environment Accounts and Statistics Division, Spatial Environmental Information System and Censuses of Population 2001.

U.S. Census Bureau: State and County QuickFacts. Data derived from Population Estimates, 2000 Census of Population and Housing, 1990 Census of Population and Housing

about these areas and;
- modelling and GIS training for local officials to assist with land use decision making.

Acknowledgments/Sources of Information

Croley, T.E., and Hunter, T.S. 1994. Great Lakes monthly hydrologic data. In *National Oceanic and Atmospheric Administration (NOAA) Technical Report*. ERL Great Lakes Environmental Research Laboratory (GLERL).

Dahl, T.E. 1990. *Wetlands losses in the U.S., 1780s to 1980s*. U.S. Department of the Interior, Fish and Wildlife Service.

Grannemann, N.G., and Weaver, T.L. *An annotated bibliography of selected references on the estimated rates of direct ground–water discharge to the Great Lakes*. U.S. Geological Survey. Water–Resources Investigations Report, pp. 98–4039.

Great Lakes Environmental Research Laboratory–National Oceanic and Atmospheric Administration. http://www.glerl.noaa.gov, last accessed June 7, 2005.

Great Lakes Water Institute–Wisconsin Aquatic Technology and Environmental Research, University of Wisconsin at Milwaukee. http://www.uwm.edu/Dept/GLWI/, last accessed June 7, 2005.

Holtschlag, D.J., and Nicholas, J.R. 1998. *Indirect ground–water discharge to the Great Lakes*. U.S. Geological Survey Open–File Report 98–579, 25 p.

Mason, D., Krause, A.E., and Ulanowicz, R.E. 2002. *Impact of exotic invertebrate invaders on food source structures and function in the Great Lakes, a network analysis approach*. http://www.glerl.noaa.gov/res/Task_rpts/2002/nsmason10-1.html, last accessed June 8, 2005.

Oberg, K.A., and Schmidt, A.R. 1994. *Measurements of leakage from Lake Michigan through three control structures near Chicago, Illinois, April–October 1993*. U.S. Geological Survey, Water–Resources Investigations Report, pp. 94–4112.

Schrank, D., and Lomax, T.J. 1998. *Urban roadway congestion: annual report 1998*. Texas Transportation Institute. The Texas A&M University System. http://mobility.tamu.edu, last accessed June 9, 2005.

SOLEC 2004 Presentations, Toronto, Ontario. 2004. *Lake Michigan.* http://www.epa.gov/solec/solec_2004/presentations/index.html, last accessed June 8, 2005.

U.S. Army Core of Engineers, Detroit District. http://www.lre.usace.army.mil/, last accessed June 8, 2005.

U.S. Environmental Protection Agency (EPA). 2004. *Lake Michigan LaMP 2004 status report*. http://www.epa.gov/glnpo/lakemich/2004update/, last accessed June 8, 2005.

U.S. Environmental Protection Agency's Office of Environmental Information. http://www.epa.gov/oei, last accessed June 9, 2005.

3.7 Lake Superior

Assessment: The status of the Lake Superior ecosystem is *mixed*.

Bald eagles, gray wolf and cormorants have recovered and forest cover has increased. Fisheries recovery indicators are also good. Some trends in contaminant loadings are showing declines while others remain constant. Invasive species continue to be a problem and remain a threat to the recovering fish population. Stresses on the system include shoreline development, habitat loss, land use change and invasive species.

Summary of the State of Lake Superior

Lake Superior is the largest freshwater lake in the world by area and third largest by volume; it averages 147 metres in depth, with a maximum depth of 406 metres. The total watershed area is 228,000 km^2 including Lake Nipigon and two major diversions. Water transparency can reach a depth of 23 metres. Lake Superior has the lowest summer surface temperature (13 degrees Celsius) and mean annual water temperature (3.6 degrees Celsius) of the Great Lakes. The watershed contains many globally rare vegetation types, including arctic alpine communities, sand dunes, and pine barrens. The three principal industries are forestry, mining and tourism. The retention time for Lake Superior is 173 years; what goes into the lake affects it for several generations. Lake Superior has eight Areas of Concern (AOCs) as shown on the map (Figure 1).

CHEMICAL CONTAMINANTS

Over the last 30 years, concentrations of nearly all measured contaminants in fish and the water column, with the exception of toxaphene, have declined in Lake Superior. Because of its remote location, limited industrial activity and large surface to

Figure 1. Lake Superior drainage basin map.
Source: Environment Canada

watershed ratio, Lake Superior receives the majority of its loading via atmospheric deposition, especially with regard to PCBs, mercury and toxaphene.

Figure 2 shows the mercury emission decreases that have occurred between 1990 and 2000. While significant reductions have occurred in products and mining, emissions from fuel combustion are virtually unchanged.

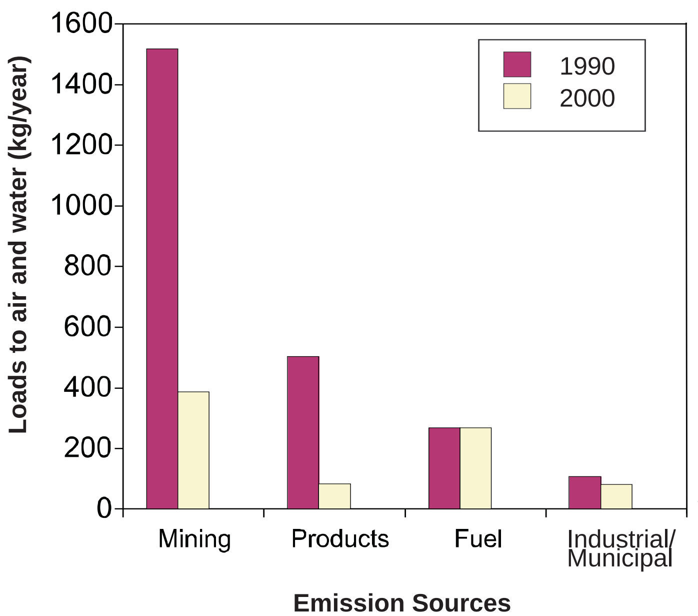

Figure 2. Mercury emissions from various sources within the Lake Superior basin.
Source: Lake Superior LaMP Chemical Committee, 2003

Water Column
Concentrations of a suite of toxic organic contaminants in water including the Lake Superior critical and lakewide remediation pollutants declined more than 50% between 1986 and 1997. Nevertheless, of the nine critical pollutants, dieldrin, mercury, PCBs and toxaphene concentrations in Lake Superior continue to exceed the most stringent water quality standards.

Gull Eggs
Herring Gull eggs have been collected and analyzed annually from the same two Lake Superior sites, Granite Island and Agawa Rocks, since 1974 for selected contaminants. Overall contaminant levels have declined. For the period 1974 to 2002, 64% of Lake Superior contaminant–colony comparisons declined as fast as or faster than they did earlier in the study, while 29% declined more slowly in recent years.

Data from 1974 to 2002 illustrates the decline in dieldrin in herring gull eggs at the Agawa rocks monitoring site. For most compounds, this site, which is in eastern Lake Superior, ranked low compared to other locations. The Granite Island site in western Lake Superior, however, ranked 3rd overall in the Great Lakes. For dieldrin and heptachlor epoxide, the two Lake Superior sites ranked the 4th and 3rd most contaminated of 15 sites studied, respectively, on the Great Lakes. For more information on contaminants in herring gull eggs, refer to the Great Lakes indicator report #115, Contaminants in Colonial Nesting Waterbirds, found later in this report.

Fish Contaminants
DDT data for lake trout collected by the U.S. Environmental Protection Agency–Great Lakes National Program Office (GLNPO) and Canada Department of Fisheries and Ocean (DFO) display a general fluctuation in concentrations from year–to–year with a recent increase in concentration. It is likely that this increase is due to a change in the sampling location rather than to an actual increase in contaminant concentration.

Concentrations of toxaphene have declined dramatically in lake trout across all Great Lakes except for Lake Superior. Lower productivity, colder temperatures and large surface area are likely responsible for higher Superior levels. Seventy–80% of Ontario's sport fish consumption advisories are due to toxaphene.

GLNPO lake trout collections show PCBs are fluctuating, although levels have dropped since 1980. The DFO lake trout data show very little recent change in mean PCB concentrations. Lake trout concentrations remain above the GLWQA criteria.

DFO smelt data continue to show a steady decline in mercury concentrations through 2002. While mercury levels are below GLWQA criteria, the trend data show continuing improvement in mercury levels for smelt. At every site monitored, mercury levels in lamprey were significantly greater than those detected in their primary prey. These data also demonstrate the significantly elevated mercury levels in lamprey from the Lake Superior system compared to other Great Lakes.

Figure 3 shows the trends for four of the Lake Superior critical chemicals. Dieldrin and chlordane appear to be leveling off. DDT appears to be increasing slightly and PCBs are fluctuating, as noted above. The number and geographic extent of sport fish consumption advisories in Lake Superior is expected to decrease as contaminant concentrations decline. However, the ecosystem requires decades to purify itself, and agencies will likely continue to issue sport fish advisories for some time.

Atmospheric Deposition
Data from the Great Lakes Integrated Atmospheric Deposition

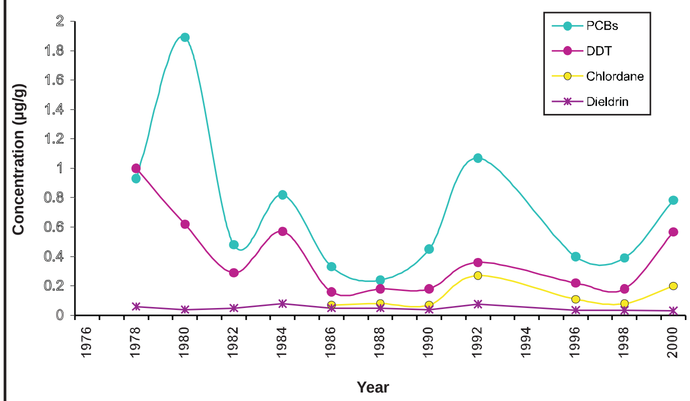

Figure 3. Apostle Island lake trout contamination trends, 1978-2000.
Source: Murphy, 2004

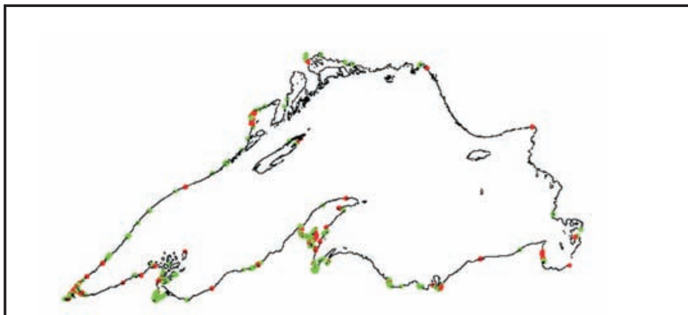

Figure 4. Man-made shorelines in the Lake Superior basin. Red circles represent riprap, sheet piling and other anthropogenic changes to the shoreline.
Source: U.S. Environmental Protection Agency, 1994 and Environment Canada, 1993

Network (IADN) indicate that levels of PCBs and banned organochlorine pesticides are declining at all master stations. For Lake Superior, the Duluth/Superior area appears to have some influence on PAHs and possibly HCB deposition to the lake. There is no apparent effect of this urban area on PCB deposition.

IADN data also suggest that the Canadian Prairie Provinces and the southern U.S. are sources of lindane to Lake Superior. PCB behavior in Lake Superior is unique with little storage in the sediments. Also there is little organic matter in the ecosystem to affect PCB levels. PCBs deposited into the lake are recycled into the food web via the plankton and also volatilized back into the atmosphere. Only 2–5% accumulates in bottom sediments.

Over many years, net volatilization of PCBs has released 26,000 kilograms to the atmosphere. Lake Superior was considered a PCB source but is now is at equilibrium with the atmosphere.

WILDLIFE AND HABITAT

Shoreline Development and Hardening

Shoreline development is one of the most pressing issues facing the Lake Superior basin today. The Keweenaw Peninsula on Michigan's Upper Peninsula has seen unprecedented housing growth in the past 20 years, mainly in recreational homes; over 50% of the homes in Keweenaw County are now classified as second homes. Population growth is greatest in the Duluth/Superior areas, Grand Marais and the Bayfield Peninsula. In Ontario, this population trend is greatest along the shorelines east and west of Thunder Bay and north of Sault Ste. Marie.

Shoreline hardening, which consists of sheet piling, riprap or other anthropogenic changes, is an increasing problem for Lake Superior. Although Lake Superior has the lowest percentage of shoreline hardening, the trend is increasing due to rapid growth of population in the areas previously mentioned (Figure 4).

Forest

Forest fragmentation and changes in forest composition are two of the seminal changes to the Lake Superior basin since settlement times. Beginning in the 1880s, U.S. forests were almost entirely clear–cut. Aspen, birch, fir and poplar have increased since logging began while spruce and pines have been severely reduced. Forest cover is anticipated to remain the same or slightly increase in the future. Forest fragmentation of hardwoods will continue to increase due to development and including road construction. The Great Lakes Forestry Alliance reported in 1995 that timber growth in Michigan, Minnesota, and Wisconsin exceeded harvest by 90% and timber volume increased from about 700 million m^3 (25 billion ft^3) in 1952 to more than 14 billion m^3 (50 billion ft^2) in 1992.

Wetlands

About 15% of the U.S. Lake Superior basin and 6–25% of the Canadian basin are wetlands (Figure 5). The greatest threats to Lake Superior's wetlands are wetland draining and filling, toxic contamination, water level regulation and site–specific stresses such as shoreline development. Other threats include invasive species and diminished water quality. Although there have been many wetland restoration success stories, it is not possible to determine if there has been a net loss or gain of wetlands because of limitations on, and lack of coordination among, current monitoring efforts. Monitoring, use of Best Management Practices and remedial actions are necessary to completely address the wetland issue.

Loss of wetland habitat has been small in some counties but most of the St. Louis River estuary wetlands at Duluth have been lost since the early 1900s. The wetlands of the Apostle Islands, Bad River and Kakagon Slough are largely intact.

There are no comprehensive estimates of coastal wetland losses for Lake Superior. Wetland loss in Ontario is low (0–25%) for most of the basin, but locally, wetland losses have been reported in the Thunder Bay and St. Marys River AOCs due to shoreline modification and urban encroachment. Wetland area around Thunder Bay has declined by over 30% since European settlement.

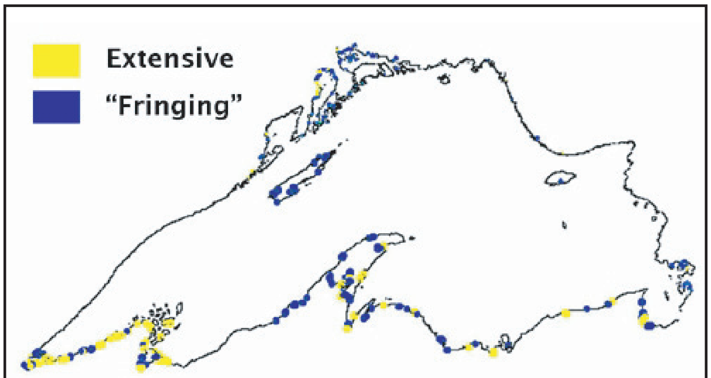

Figure 5. Lake Superior shoreline wetlands. Fringing wetlands are marsh communities, characteristically found in shallow water coves protected from wind and waves. They closely border the shore to form a narrow belt of aquatic vegetation. Extensive wetlands are larger (up to 1 to 2 km long) and occupy shallow coves with stream outlets.
Source: U.S. Environmental Protection Agency, 1994 and Environment Canada, 1993

Lake Superior shoreline wetlands are a particular concern in Ontario, given their scarcity and proximity to developed areas. The potential for further development at Cloud Bay, Sturgeon Bay and Pine Bay threatens wetlands.

Wildlife

Habitat changes on the landscape, as well as harvest and management of select species, have created some dramatic changes in wildlife communities over the past 150 years. Ungulates, wolves and furbearers were hunted to near extinction but are now rebounding.

Successful reintroduction of peregrine falcons is also underway within the basin. Cormorants and herring gulls are recovering after being decimated by toxic contaminants in the 1970s.

Caribou in Canada and Canada lynx in the U.S. are still scarce although recovery planning is underway for these and a number of other species at risk in the basin, i.e. piping plover and wood turtle.

Eighteen animal species found in the Lake Superior watershed, including mammals, birds, insects and herptiles, are listed by Canada and/or the U.S. as endangered. In addition, there are 400 species in the basin listed by provincial or state jurisdictions as endangered, threatened, or of special concern. Of the 400 species, nearly 300 are plants. The preparation of recovery plans or conservation strategies is underway for 26 species.

Little work has been done to monitor and classify the status of amphibians and reptiles in comparison to other vertebrates, although the planning of a basin–wide monitoring program for herptiles is underway. Thirty–seven species of reptiles and amphibians have been documented including seven salamanders, 12 frogs, six turtles, two lizards and one snake. As with many vertebrates, the widespread changes in habitat cover across the landscape have had a dramatic effect on the community composition of amphibians and reptiles. However, local population declines of many amphibians (Table 1) are becoming a concern worldwide. Many possible reasons exist for these declines; monitoring programs are being initiated to document trends.

Species	Relatively Stable	Increasing	Decreasing	State Endangered	Special Concern	No Trend Data Available
Wood frog	●	■				
Northern leopard frog	●		● ■			
Pickerel frog			■			
Mink frog						● ■
Green frog	● ■					
Chorus frog	■					
Northern spring peeper	●		■			
Eastern gray treefrog	● ■					
Cope's gray treefrog			■			
Blanchard's cricket frog					●	
American toad	● ■					
Blue-spotted salamander	● ■					
Eastern tiger salamander			●			
Spotted salamander	■					
Four-toed salamander					■	
Redback salamander	●					
Mudpuppy						● ■

■ Wisconsin ● Minnesota

Table 1. Status of amphibian species found in the Lake Superior basin in the states of Minnesota and Wisconsin.
Source: Casper, 1998, Moriarty 1998, and Mossman *et al*., 1998

Aquatic Communities

The fish community of Lake Superior is generally good and remains relatively intact compared to the other Great Lakes. Through rehabilitation, lake trout stocks have increased substantially and may be approaching ancestral states. Although the siscowet shows high levels of toxic contaminants, this has not interfered with reproduction (Figure 6). There are more naturally reproducing lake trout in Lake Superior than there are in all the other Great Lakes combined. These trout are reproducing on their own with very little management needed. There are good stocks of whitefish and herring.

Natural reproduction supports most salmonid populations. Some

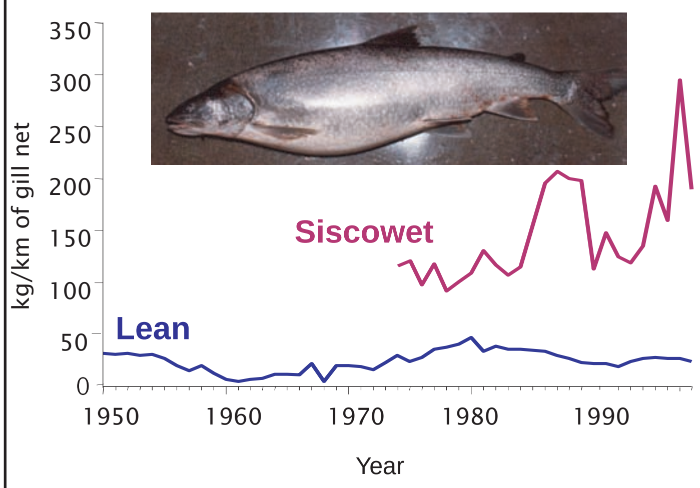

Figure 6. All forms (stocked and non-stocked) of lake trout abundance, 1950-1998.
Source: Great Lakes Fishery Commission

near shore fish populations, especially lake sturgeon, walleye and brook trout, remain below historical levels. Non–native species continue to be introduced to Lake Superior, although the fish community appears to contain enough buffering capacity to withstand and minimize the current levels of non–native species. Sea lampreys still kill thousands of lake trout each year. Round gobies and ruffe have colonized some areas and have the ability to negatively impact the near shore cool–water fish community.

Aquatic Habitat

Nearshore and open water habitat is very good, leading to abundance of trout, and good stocks of whitefish and herring. The problem is mostly in the tributaries and embayments, especially in the Areas of Concern. Lake Superior tributaries have borne the brunt of most of the habitat destruction and loss. These tributaries remain significantly degraded by such stressors as agriculture, mining, hydroelectric dams, industrial effluents and waste, wetland dredging and filling, non–point source pollution, shoreline development and use practices that lead to increased runoff and erosion. There is now naturally reproducing sturgeon, walleye and brook trout. Although the habitat is sufficient to help them increase in abundance, populations are not near historic levels because of past habitat destruction. All three species have active rehabilitation programs and resource management activities.

Invasive Species

Except for sea lamprey, the non–native species in Lake Superior have been manageable up to this point. Lake Superior, however, has the highest ratio of non–native species to native species of all the Great Lakes. Lake Superior represents the dead–end for shipping for many invasive species as it is at the end of the

Lake Superior Statistics	
Elevation[a]	
feet	600
metres	183
Length	
miles	350
kilometres	563
Breadth	
miles	160
kilometres	257
Average Depth[a]	
feet	483
metres	147
Maximum Depth[a]	
feet	1,332
metres	406
Volume[a]	
cu.mi.	2,900
km^3	12,100
Water Area	
sq.mi.	31,700
km^2	82,100
Land Drainage Area	
sq.mi.	49,300
km^2	127,700
Total Area	
sq.mi	81,000
km^2	209,800
Shoreline Length[b]	
miles	2,726
kilometres	4,385
Retention Time	
years	173
Population: USA (2000)[c]	663,606
Population: Canada (2001)	178,656
Totals	842,262
Outlet	St. Marys River

[a] measured at low water datum
[b] including islands
[c] 2000 population census data were calculated based on the total population of each county, either completely or partially, located within the watershed.

Sources:
The Great Lakes: An Environmental Atlas and Resource Book

Statistics Canada, Environment Accounts and Statistics Division, Spatial Environmental Information System and Censuses of Population 2001.

U.S. Census Bureau: State and County QuickFacts. Data derived from Population Estimates, 2000 Census of Population and Housing, 1990 Census of Population and Housing

lakes. There is nothing to make us think that Lake Superior will not have its own singular invasive species problem (i.e., such as zebra mussels in the lower lakes) and, unless we do something fairly proactive fairly soon, we could have a significant problem on our hands.

Numerous invasive insect, animal and plant species have been also introduced to the Lake Superior basin. A few examples of species likely to have significant impacts include: gypsy moth, Asian long–horned beetle, rusty crayfish and exotic buckthorns. One of the most potentially devastating invasive species is the emerald ash borer. Now located in Lower Michigan and Ontario, it remains outside the Lake Superior basin for now. There is no known natural control or treatment at this time, so it could potentially devastate inland and coastal wetland ecosystems that may contain large areas of ash trees.

Future and Emerging Management Issues

Lake Superior has many existing pressures on its system which will continue to pose problems now and in the future including: continued degradation of tributary and embayment aquatic habitat, shoreline and other habitat development, continued introduction and impacts of non–native species, and continued release and deposition of critical pollutants.

Positive action is now occurring in the Lake Superior basin. The U.S. and Canadian governments have recently reaffirmed their commitment to the Zero Discharge Demonstration Program. The Lake Superior cooperative monitoring program has been working to develop priorities for the 2005–2006 Lake Superior monitoring year. Many habitat inventory, assessment and monitoring programs are being implemented. Rehabilitation of critical aquatic habitats is underway and several wildlife and fish species have been restored.

Global warming, climate change, increasing water temperature, large–scale water export, other chemicals of emerging concern (such as pharmaceuticals and personal health products), and newly proposed or expanded industrial facilities are other critical issues that will require attention now and in the future.

Acknowledgments/Sources of Information

Casper, G.S., Moriarty, J.J., Mossman, M.J., et al. 1998. Status and conservation of midwestern amphibians. In University of Iowa Press, ed. M.J. Lannoo, pp. 507. Iowa City, IA.

Ebener, M.P. (ed.). 2005. The state of Lake Superior in 2000. Great Lakes Fishery Commission Special Publication. http://www.glfc.org/lakecom/lsc/stateofsuperior/index.htm, last accessed June 9, 2005.

Environment Canada. 1993. Environmental Sensitivity Atlas for Lake Superior's Canadian Shoreline, Conservation and Protection Branch.

Lake Superior Lakewide Management Plan (LaMP) Chemical Committee, 2003.

Murphy, Elizabeth. 2004. U.S. Environmental Protection Agency, Great Lakes Fish Monitoring Program, Great Lakes National Program Office. Chicago, IL.

SOLEC 2004 Presentations, Toronto, Ontario. 2004. Lake Superior. http://www.epa.gov/solec/solec_2004/presentations/index.html, last accessed June 8, 2005.

U.S. Environmental Protection Agency. 1994. Inland Spill Response Mapping Project, Digital Database.

U.S. Environmental Protection Agency. 2004. Lake Superior Lakewide Management Plan (LaMP) 2004. http://epa.gov/glnpo/lakesuperior/2004/, last accessed June 8, 2005.

4.0 Indicator and Indicator Category Assessments

This section of the **State of the Great Lakes 2005** provides overviews and assessments of the Great Lakes basin ecosystem based on reports for 56 of 81 indicators. There are also 4 additional progress indicator reports included in this section. These reports were prepared because data were readily available basin-wide, or for some portion of the basin. Approximately 100 Great Lakes experts from more than 35 governmental and non-governmental organizations were directly involved as primary authors for these indicator reports. Countless others contributed to the preparation, analysis, interpretation and assessment of data for these indicator reports.

The concept of indicator categories is new for this report with indicators grouped into one or more of nine categories. This has been done to improve the overall reporting and assessment process for determining the health of the Great Lakes basin ecosystem and its components. Within most of the main categories are sub-categories to further delineate issues or geographic areas.

The categories and sub-categories are:

- **Contamination**
  - Nutrients
  - Toxics in Biota
  - Toxics in Media
  - Sources and Loadings
- **Biotic Communities**
  - Fish
  - Birds
  - Mammals
  - Amphibians
  - Invertebrates
  - Plants
- **Non-Native Invasive Species**
  - Aquatic
  - Terrestrial
- **Coastal Zones**
  - Nearshore Aquatic
  - Coastal Wetlands
  - Terrestrial
- **Aquatic Habitats**
  - Open Lakes
  - Groundwater
- **Human Health**
- **Land Use-Land Cover**
  - General
  - Forest Lands
  - Agricultural Lands
  - Urban/Suburban Lands
  - Protected Areas
- **Resource Utilization**
- **Climate Change**

Some of these categories are under-development and will require additional indicators and subcategories to become complete. For example, the Aquatic Habitats category should be expanded to include indicators of riverine/tributary habitats as well as inland lakes. For more detailed information, including additional proposed subcategories and a listing of the indicators within each category, please see the report, *The Great Lakes Indicators Suite: Changes and Progress 2004*, available on-line at: www.epa.gov/glnpo/solec.

In most cases the indicator reports, which include assessments of conditions and trends, were prepared by acknowledged experts from the Great Lakes community. The same four rankings that were applied to the assessments of lakes and rivers in the previous section (Good, Fair, Poor and Mixed) were used to characterize each indicator assessment. The same four ecosystem trends (Improving, Unchanging, Deteriorating and Undetermined) were also used. In addition to the assessment, each indicator report includes the purpose, the ecosystem objective, the state of the ecosystem, pressures and management implications.

In some cases, the indicators do not warrant a new report every two years. For these indicators (14 of them) the reports are 'brought forward' from a previous reporting cycle. When an indicator report has been 'brought forward', it is noted with the year in which it was prepared.

Category and sub-category overviews have also been prepared by experts from the Great Lakes community who did not author any of the indicator reports within the group. These overviews include the same ranking system and trends used in other sections of this report, and they also include a short justification of how the expert(s) arrived at that ranking (including pointing out gaps and inadequacies in the data). Because many of the indicators are associated with more than one category, the indicator reports are arranged in numeric order according to indicator ID number in Section 4.2.

Considerable progress has been made since the **State of the Great Lakes 2003** reporting cycle for previously under-developed indicator categories. The indicators for Coastal Wetlands have now been defined, refined, and in many cases reported on. Groundwater indicators have also been refined, and, in one case a complete basin-wide report has been prepared while for the others, case studies have been piloted for their ability to be reported effectively. The indicators for Forest Lands were the subjects of debate among various forestry stakeholders in the Great Lakes basin, but a consensus approach was achieved, and a detailed report for the first of the sub-groupings was submitted as indicator #8500 Forest Lands-Conservation of Biological Diversity. Additional details of the process and results of deliberations of the Forest Lands working group are documented in a companion report, *Developing SOLEC Forest Indicators*, available on-line at www.epa.gov/glnpo/solec.

In this section, the category and subcategory overviews are presented first (Section 4.1), along with a listing of the indicators (and their indicator identification numbers) that were included in each category. Because many of the indicators are relevant to more than one category, the individual indicator reports are presented in the numeric order of their identification numbers following the overview discussions. This arrangement of indicators should facilitate the rapid location of any indicator report by the reader without needing to explore multiple bundles to find a particular report.

See list of acronyms (Section 7.0) for explanation of unfamiliar chemicals, agencies or units.

4.1 Category Assessments

Contamination Assessment

Assessment
Ecosystem Condition: Mixed
Ecosystem Trajectory: Improving

State of the Ecosystem
Analysis of contaminant indicators suggests an overall improvement in the ecosystem from that of thirty years ago. There is a marked reduction in concentrations of toxic chemicals in most media, and many indicator species demonstrate improvements since the beginning of Great Lakes monitoring programs. Management activities have resulted in the regulation of many sources of contaminants and the reduction of loadings of these contaminants into the Great Lakes basin. Although the overall health of the ecosystem shows signs of improvement, many ecosystem objectives have yet to be achieved.

Progress toward ecosystem restoration is uneven because various environmental and historical factors affect the ability for recovery. For example, many indicator species still contain concentrations of persistent bioaccumulative toxic chemicals above established guidelines, and concentrations of phosphorus in some areas within the Great Lakes continue to exceed targets.

Other factors may inhibit further reductions of concentrations and impacts of contaminants in the ecosystem. To maintain future reductions in the emissions of contaminants, for example, the implementation of actions that support sustainability may be needed to offset the by-products of population growth and urban sprawl. Exporting sources of pollution to locations outside the Great Lakes basin may result in local improvements, but such actions would cause environmental degradation elsewhere. Global events, such as climate change and long range transport, will require the cooperation of multiple jurisdictions to affect change. Also, the presence of some chemicals, such as PBDEs and PFOS, is raising concern as we grow to understand their effects on the health of the ecosystem and all of its inhabitants.

<u>Nutrients:</u> *Not Assessed*
The analysis of the Nutrients subcategory is incomplete because insufficient information was available for some of the indicators. Although an assessment was made on *Phosphorus Concentrations and Loadings*, this is not adequate for a general assessment of all the indicators in this category.

Analysis of total phosphorus concentrations in all five lakes suggests an overall improvement in the ecosystem from the 1970s. There also has been a marked reduction in total phosphorus loadings to each of the Great Lakes since the 1970s and 1980s. Most estimates of phosphorus loadings were discontinued in the early 1990s, however, as objectives appeared to have been attained for maximum external loadings rates. Management activities that brought about these reductions focused on limiting the amount of phosphorus in effluent from municipal waste water treatment plants, restricting the amount of phosphorus in laundry detergents, and reducing non-point source agricultural run off through improved farming practices.

From the time of the introduction of controls on nutrient loadings to the present, total phosphorus concentrations have decreased or held steady in all the Great Lakes except for Lake Erie, where total phosphorus concentrations increased during the 1990s. Estimates of loadings to Lake Erie through the 1990s showed that the external loads were apparently not increasing. Total phosphorus concentration increases in Lake Erie may be due to changes in the internal processing of phosphorus, however, which may have been brought on by the introduction of non-native species, particularly the zebra and quagga mussels. Thus, the phosphorus concentrations in the open lake ecosystems have decreased to (Lakes Michigan and Ontario) or remain unchanged at or below (Lakes Superior and Huron) the target levels. The ecosystem objectives for phosphorus concentrations in Lake Erie have not been achieved.

<u>Toxic Chemicals in Biota:</u> *Mixed, Improving*
Persistent toxic substances that have been associated with, or have the potential to cause, deleterious environmental impacts because of their presence in the Great Lakes basin have generally declined in biota over the past thirty years. Levels of PCBs, DDT and other pesticides have declined dramatically in trout, salmon, herring gull eggs, and spottail shiners. In many cases, however, levels still exceed health-based criteria and/or guidelines (e.g., fish advisories remain in place on all five Great Lakes for mercury, PCBs, and various organochlorine pesticides).

With regard to mercury, monitoring data from herring gull communities and fish generally indicate a 50% decline in mercury levels throughout the Great Lakes since the late 1970s. There were declines in mercury levels in biota at a number of locations in the Great Lakes as a result of cessation of wastewater discharges. More recent data show the mercury levels in biota to be declining slightly or remaining about the same depending on location and data set. The relationship of atmospheric deposition, in general, and North American mercury emissions, in particular, to fish tissue levels of methyl mercury cannot be quantified at this time.

In terms of gross ecological effects (e.g., egg shell thinning, population declines) most species have recovered. For example, bald eagles continue to recover and occupy additional territories, but evidence of toxics-related developmental deformities persists. Recent measurements in more subtle physiological and genetic endpoints, such as male-biased sex ratio in hatchlings, feminization in males, and suppressed immune system disorders, indicate the need to investigate endocrine disrupting chemical effects in the basin.

Some contaminants, such as PBDE, have been increasing exponentially in some biota (e.g., trout, gull eggs), while other chemicals, such as PFOS/PFOA, have been detected in some biota and in breast milk in North American women. More research needs to be conducted to understand the health impacts of these emerging chemicals in the basin.

<u>Toxic chemicals in Media:</u> *Mixed, Improving*
Overall, there has been significant progress in reducing concentrations of most chemicals of concern in the Great Lakes basin. Management efforts to control emissions of critical pollutants have resulted in reductions in their concentrations in the Great Lakes. Regulations in the electricity generating industry have seen success in reducing sulfur dioxide emissions, and they are expected to reduce atmospheric loadings of mercury. Ground level ozone and fine particulate matter remain concerns in the Great Lakes basin, and acid deposition continues to be a significant problem for many inland lakes in the Great Lakes watershed.

Concentrations of chlorinated organic contaminants are declining in offshore water samples, and in certain cases (e.g., dieldrin, hexachlorobenzene, octachlorostyrene and mirex) have decreased in the Niagara River by 70%. Although conditions now are better than they were twenty years ago, progress has not been uniform, and some areas remain with significant contamination. Legacy sources of toxic chemicals in the sediment persist in affecting water quality in areas of Lakes Ontario, Erie and Michigan.

Although management actions have resulted in decreased emissions of most chemicals of concern, there remains a legacy of degraded sites, long range transport, population growth and urban sprawl that may affect additional future emission reductions. Concentrations of some emerging chemicals of concern are increasing and could pose future stressors to the ecosystem.

<u>Sources and Loadings:</u> *Mixed, Improving*
There has been a marked reduction in sources and loadings of contaminants into the Great Lakes ecosystem over the last thirty years. Collaboration between governments and the private sector have been largely responsible for source reductions of lead, sulfur dioxide and carbon monoxide. Many municipalities on both sides of the basin have begun to enact restrictions on the use of pesticides for cosmetic lawn care purposes, thereby regulating a source of endocrine disruptors. Voluntary pollution prevention activities, technology-based pollution controls, and chemical substitution have aided in the reduction of toxic substances into the Great Lakes.

While management actions have resulted in reductions of emissions, and presumably loadings, of many chemicals of concern, there exist some continuing problems: additional reductions in nitrous oxide emissions will be required to further combat air quality issues and acid deposition; the rate of reduction of the concentration of PCBs in air, fish and other biota appears to have slowed or stopped in many cases; PAHs and metals continue to be emitted in large quantities, especially near large population centers; and residual contaminants continue to affect ambient concentrations in the ecosystem. Factors like population growth, climate change and long range transport will affect future management actions in terms of source management and loadings reductions.

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Oscar Chen-See, Environmental Protection Branch, Environment Canada.

CONTAMINATION

ID #	Indicator Name	2005 Assessment (Status, Trend)
Nutrients		
111	Phosphorus Concentrations and Loadings	Mixed, ?
7061	Nutrient Management Plans	Not Assessed
Toxics in Biota		
114	Contaminants in Young-of-the-Year Spottail Shiners	Mixed, →
115	Contaminants in Colonial Nesting Waterbirds	Mixed, →
121	Contaminants in Whole Fish	Mixed, →
124	External Anomaly Prevalence Index for Nearshore Fish	Poor/Mixed, ?
4177	Biologic Markers of Human Exposure to Persistent Chemicals	Mixed, ?
4201	Contaminants in Sport Fish	Mixed, →
4506	Contaminants in Snapping Turtle Eggs	Mixed, Trend Not Assessed
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, →
8147	Population Monitoring and Contaminants Affecting the American Otter	Mixed, Trend Not Assessed (2003 report)
Toxics in Media		
117	Atmospheric Deposition of Toxic Chemicals	Mixed, → & ◆
118	Toxic Chemical Concentrations in Offshore Waters	Mixed, →
119	Concentrations of Contaminants in Sediment Cores	Mixed, →
4175	Drinking Water Quality	Good, ◆
4202	Air Quality	Mixed, →
9000	Acid Rain	Mixed, →
Sources and Loadings		
117	Atmospheric Deposition of Toxic Chemicals	Mixed, → & ◆
4202	Air Quality	Mixed, →
9000	Acid Rain	Mixed, →

Status				Trend			
(green)	(yellow)	(red)	(tan)	→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Biotic Communities Assessment

Assessment
Terrestrial [forests]
Ecosystem Condition: Mixed
Ecosystem Trend: Improving

Aquatic - Open Waters
Ecosystem Condition: Mixed
Ecosystem Trend: Undetermined

State of the Ecosystem
Terrestrial
Forest Cover
The total area of forested lands increased across the Great Lakes basin in recent decades, a sure and positive sign that water quality and hydrological patterns of surface runoff in recently-forested watersheds might also be improving. Total forest cover of at least 60% by area for southern Ontario streams is anticipated to contribute to the restoration of much of the terrestrial, aquatic and groundwater resources in urban catchments that presently have little forest cover. Increases in total area of riparian vegetation will improve land-water interfaces along lakes and streams, as well as re-establish associated avian and mammalian species. Forested corridors will also provide transport routes for wildlife, and they could be the basis for recreational trail systems for people.

Aquatic

Fish
The indicator for salmon & trout reports a mixed/improving assessment across the Great Lakes basin. Lake trout stocking in Lake Huron has re-established a significant biomass, and stocking effectiveness remains high. Adequate spawning stocks (>age 6), however, are not yet established because predation by sea lamprey may be limiting recovery. In Lake Superior in 2003, sea lamprey consumed as much biomass as was taken by all fishing activities. As well, thiamine-deficiency in salmonids feeding on alewife remains problematic. In Lake Ontario, chinook salmon abundance is stable, possibly because natural reproduction is contributing to higher survival rates of young fish. The condition of the spawning chinook has deteriorated, however.

Walleye populations are threatened by losses of habitat for spawning and early life stages (caused by changes in land-use) and shifts in energy transfers in the food web (caused by non-native species). Despite these negative pressures, sport catch-per-unit-of-effort for walleye in Lake Erie increased in 2003, along with a concomitant increase in mean age of fish in both angling and commercial fisheries. In Lake Ontario, younger year-class numbers improved slightly, so that age 3 and older fish populations should remain steady at least for the next several years.

Preyfish populations are in various stages of deterioration, especially where most of the biomass has been non-native smelt and alewife. However, native forage species like bloater and herring are showing signs of recovery.

Lake trout, the keystone species for Great Lakes oligotrophic waters, is having variable success of recovery, but the trend is improving. For example, in Lake Ontario, lake trout reproduction was more successful in 2003 than in the previous five years; two new spawning sites were found in Lake Huron; and in the Lake Erie Eastern Basin, 2003 was the third consecutive year in which assessment catches increased. However, abundance of some mature lake trout stocks continues to decline because smaller prey-fish biomasses may not support larger lake trout populations, and *Dreissena* are adversely impacting spawning shoals.

Lake sturgeon has a potential for spectacular recovery after many years of decline and extirpation in part of its range. Recovery can result from more restrictions on fishing, from habitat repair, and from the removal of dams on tributaries. The latter can bring mixed blessings because more unrestricted streams can also provide more spawning habitat for sea lamprey.

Botulism E in various fish species may cause mortality. Live fish, especially round goby, and perhaps other non-native species, may be the transfer link to waterbirds. Infected fish display loss of equilibrium and surface breaching, becoming more susceptible to capture by predating birds.

Non-native species remain a wild card in any recovery program.

Birds
General decreases in the abundances of wetland-dependant birds suggest that quality and quantity of wetlands continue to deteriorate. Some birds are also detrimentally affected by regulated water levels. Loss of quality wetlands habitats, combined with toxic chemical levels that may affect physiological functions, indicates continuing stress for wetland bird communities. Bald eagle populations continue to expand into new territories, although deformities related to toxic substances still occur.

Mammals
Otters are still threatened by contaminants in food web.

Amphibians
There has been a general decline in populations of American toad and some frog species, likely because of continuing losses of suitable habitats.

The value of groundwater for certain life-history stages of brook trout (and, by extension, several species of amphibians) is demonstrated by spawning surveys on a tributary to the Grand River in southern Ontario. Uncontrolled pumping of water from wells and groundwater-dependant streams threaten survival and reproduction of many groundwater-dependant species.

Invertebrates

Populations of native unionid mussels have been severely depleted since the arrival of dreissenids, particularly in Lake Erie and Lake St Clair where 99% of their former abundance has been lost. Remaining Great Lakes populations are dispersed and fragmented, surviving mostly in wetlands refugia.

Hexagenia (mayfly) populations appear to be improving, a welcomed sign because this genus is a major food item that transfers energy from organic material in surficial sediments to fish in mesotrophic waters (e.g., Lake Erie). However the group is still susceptible to releases of untreated sewage, and its relationship with the *Dreissena* species is unknown.

The benthic amphipod, *Diporeia*, is an excellent bio-indicator of offshore waters >30 m deep, and it is an excellent food source for salmonids and lake whitefish. *Diporeia* are currently in a state of dramatic decline in Lakes Michigan, Ontario and Huron, and they are completely gone or very rare in Lake Erie. An ecological association with dreissenids is suspected but not yet clearly identified.

Acknowledgments

Doug Dodge, Streambenders.

BIOTIC COMMUNITIES

ID #	Indicator Name	2005 Assessment (Status, Trend)
Fish		
8	Salmon and Trout	Mixed, Improving
9	Walleye	Good, Unchanging
17	Preyfish Populations	Mixed, Deteriorating & Improving
93	Lake Trout	Mixed, Deteriorating & Improving
125	Status of Lake Sturgeon in the Great Lakes	Mixed, ? (Undetermined)
4502	Coastal Wetland Fish Community Health	Not Assessed
Birds		
115	Contaminants in Colonial Nesting Waterbirds	Mixed, Improving
4507	Wetland-Dependent Bird Diversity and Abundance	Mixed, Deteriorating
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, Improving
Mammals		
8147	Population Monitoring and Contaminants Affecting the American Otter	Trend Not Assessed (2003 report)
Amphibians		
4504	Coastal Wetland Amphibian Diversity and Abundance	Mixed, Deteriorating
7103	Groundwater Dependant Plant and Animal Communities	Not Assessed
Invertebrates		
68	Native Freshwater Mussels	Not Assessed
104	Benthos Diversity and Abundance - Aquatic Oligochaete Communities	Trend Not Assessed (2003 report)
116	Zooplankton Populations	Trend Not Assessed (2003 report)
122	Hexagenia	Mixed, Improving
123	Abundances of the Benthic Amphipod *Diporeia* spp.	Mixed, Deteriorating
4501	Coastal Wetland Invertebrate Community Health	Not Assessed
Plants		
109	Phytoplankton Populations	Trend Not Assessed (2003 report)
4862	Coastal Wetland Plant Community Health	Mixed, ? (Undetermined)
8500	Forest Lands - Conservation of Biological Diversity	Mixed, Improving

Status				Trend			
(green)	(yellow)	(red)	(tan)	→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Non-Native Invasive Species Assessment

Assessment
Aquatic
Ecosystem Condition: Mixed
Ecosystem Trend: Unchanging

Terrestrial
Not Assessed

State of the Ecosystem
The status of invasive species in the Great Lakes is *Mixed, Unchanging* for non-native aquatic species, based on an assessment of two indicators. The non-native species indicator is broad and has not yet been fully developed for terrestrial species. However, from the information reported and other anecdotal evidence, we can expect the number of non-native invasive species to increase in both aquatic and terrestrial components of the Great Lakes basin ecosystem.

<u>Aquatic</u>
The Great Lake Fishery Commission (GLFC) and fishery management agencies have agreed on target abundances for sea lamprey populations in each lake, at which level the mortality rates of lake trout should be reduced to tolerable levels. Sea lamprey abundance is currently within the target range for Lake Ontario and Lake Erie, but populations have been increasing in Lake Michigan and Lake Superior and have exceeded the target range since 1998 and 1999, respectively. In Lake Huron, abundances fluctuate year-to-year, but over the past 20 years, the population level was within the target range only once, in 2002. The GLFC has increased stream treatments and lampricide applications in response to the increasing abundances from 2001 through 2004. Efforts are being focused on research and development of alternative control strategies, and computer models are being used to best allocate treatment resources. The potential for sea lamprey to colonize new locations, however, is increased with improved water quality and removal of dams from tributaries that provide spawning habitat. Any areas newly infested with sea lamprey will require some form of control.

The total number of non-native species introduced and established in the Great Lakes has increased steadily since the 1830s, but the number of ship-introduced species has increased exponentially during the same time period. Human activities associated with shipping are responsible for over half of non-native species introductions to the Great Lakes. Contrary to expectations, the rate of introductions increased following initiation of voluntary ballast management guidelines in 1989 and mandated in 1993. Recent studies indicate the Great Lakes may vary in vulnerability to invasion in space and time. Of particular concern are aquaria, garden ponds, bait fish and live food fish markets. In the United States, the Lacey Act prohibits interstate transport of some aquatic nuisance species. However, there are currently shortcomings in legal safeguards relating to commerce in exotic live fish.

Researchers are studying the 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 invasions. Without measures that effectively eliminate or minimize the role of ship-borne and other emerging routes of entry, we can expect the number of non-native species in the Great Lakes to continue to rise, with an associated loss of native biodiversity and an increase in unpredicted ecological disruptions.

<u>Terrestrial</u>
Invasive non-native species destroy wildlife habitats and crowd out competitors, thereby threatening biodiversity. The negative impact of a wide range of non-native species, such as reed canary grass, garlic mustard, common buckthorn, and purple loosestrife, has been documented throughout the Great Lakes basin. However, the extent of invasion by other terrestrial non-native species is not well known. Some efforts are underway in the Great Lakes basin to set priorities for prevention and control of terrestrial invasive species and for public education. Additional activities are expected to lead to the formulation of a protocol for tracking invasive, non-native terrestrial species.

Acknowledgments
Karen Rodriguez, U.S. Environmental Protection Agency.

INVASIVE SPECIES

ID #	Indicator Name	2005 Assessment (Status, Trend)
Aquatic		
18	Sea Lamprey	Good/Fair, Improving (→)
9002	Non-Native Species (Aquatic)	Poor, Deteriorating (←)

Status				Trend			
(green)	(yellow)	(red)	(tan)	→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Coastal Zones Assessment

Assessment
Ecosystem Condition: Mixed
Ecosystem Trend: Deteriorating

State of the Ecosystem
Overall, the Great Lakes Coastal Zone, comprised of nearshore aquatic, coastal wetland, and nearshore terrestrial habitats, is considered *Mixed, Deteriorating*, based on an assessment of eleven indicators. The nearshore aquatic area is considered Mixed, Deteriorating because of continued shoreline hardening; the status of coastal wetlands is Mixed, Deteriorating due to continued anthropogenic pressures that include habitat loss and degradation, non-native species, and contamination; and the nearshore terrestrial zone is considered Mixed, Deteriorating or Undetermined based on an evaluation of the degraded condition of sand dunes and beaches, rocky shores and alvars.

Although progress is being made in setting up a long term monitoring program for coastal wetlands, and collaborators are working basin-wide to better understand both nearshore aquatic and terrestrial ecosystems, much work has yet to be done to get to a point where indicators are meaningful to assess ecosystem status. Clearly, the work of the last couple of years by coastal wetlands and islands scientists and managers has led to an appreciation of the roles of these habitats in maintaining water quality and ecosystem health.

Nearshore Aquatic: Mixed, Deteriorating
Shoreline hardening is the construction of sheet piling, rip rap, or other erosion control structures. Shoreline hardening directly destroys natural features and aquatic habitats and disrupts biological communities that depend upon the transport of shoreline sediment by lake currents. The effect is the destruction of habitat and the disruption of shoreline sediment transport needed to nourish aquatic habitats. 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.

Coastal Wetlands: Mixed, Deteriorating
An initial assessment of the area of coastal wetlands, by type, showed that 216,743 hectares (ha) have been identified within the Great Lakes and connecting rivers up to Cornwall, Ontario. 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. In Lakes Superior, Huron and Michigan, barrier protected coastal wetlands are a prominent feature, accounting for over 50,000 ha. In Lake Erie, protected embayment wetlands account for over one third of the total 25,127 ha of coastal wetlands. In Lake Ontario, barrier protected and drowned river mouth coastal wetlands account for 14,164 ha, approximately two thirds of the total coastal wetland area. The St. Clair River delta, where the St. Clair River outlets into Lake St. Clair, is the most prominent single wetland feature in the Great Lakes, accounting for over 13,000 ha. The Upper St. Lawrence River also supports numerous small embayment and drowned river mouth wetlands associated with the Thousand Island region and St. Lawrence River shoreline. These estimates of coastal wetland extent, particularly for the upper Great Lakes, are acknowledged to be incomplete.

In a test application of an Index of Biotic Integrity (IBI) for wetland invertebrate communities, those from Northern Lakes Michigan and Huron generally produced the highest scores. In the drowned river mouth wetlands of eastern Lake Michigan, invertebrate communities show a linear relationship with latitude that reflects anthropogenic disturbances. However, investigators concluded that natural water level changes were likely to alter wetland invertebrate communities and invalidate IBI metrics.

The composition of fish communities is significantly related to plant community type within wetlands and, within plant community type, is related to amount of anthropogenic disturbance. There are no data to suggest that fish communities of any single Great Lake are more impacted than those of any other. However, of the 61 wetlands sampled in 2002 from all five lakes, those in Lakes Erie and Ontario tended to have more wetlands containing cattail communities, whose fish communities tended to have lower richness and diversity than fish communities found in other vegetation types. Wetlands found in northern Lakes Michigan and Huron tended to have relatively high quality coastal wetland fish communities.

Trends in amphibian occurrence were assessed for eight species commonly detected on Marsh Monitoring Program routes (469 routes throughout the Great Lakes basin). Statistically significant declines in occurrence trends were detected for the American Toad, Chorus Frog, Green Frog, and Northern Leopard Frog. Further data are required to conclude whether Great Lakes wetlands are successfully sustaining amphibian populations.

From 1995 through 2002, 53 species of birds that use marshes for feeding, nesting or both were recorded by Marsh Monitoring Program volunteers at 419 routes throughout the Great Lakes basin. Tree Swallows and Barn Swallows were the most common species that typically feed in the air above marshes. The Red-winged Blackbird was the most commonly recorded marsh nesting species. Species with significant basin-wide declines were the Least Bittern, Black Tern, Marsh Wren, undifferentiated American Coot/Common Moorhen (their calls are difficult to distinguish), Pied-billed Grebe, Red-winged Blackbird, and

Virginia Rail. Statistically significant basin-wide population increases were observed for the Willow Flycatcher, Common Yellowthroat, and Mallard. In the coastal wetlands of Lakes Erie, Michigan, and Huron, population trends of the American Coot, Least Bittern, Marsh Wren, Pied-billed Grebe, Sora, Swamp Sparrow, and Virginia Rail were positively correlated with water levels, and thus, seemed to track fluctuations in Great Lakes water levels.

The state of coastal wetland plant communities is quite variable across the Great Lakes basin, but trends in wetland health based on plants are not well established. However, there is evidence that the plant component in some wetlands is deteriorating in response to extremely low water levels, but this deterioration is not seen in all wetlands. In general, there is slow deterioration in many wetlands as shoreline alterations allow the introduction of non-native species. On the other hand, the turbidity of the southern Great Lakes has been reduced by zebra and quagga mussels, resulting in improved submergent plant diversity in many wetlands.

Although not basin-wide, available data generally indicate a decline in contaminants in snapping turtle eggs, but in some locations contaminants continue to exceed guidelines. Contaminants in snapping turtle eggs change over time and among sites, with significant differences between contaminated and reference sites. Rates of abnormal development of snapping turtle eggs from 1986-1991 were highest at all four Lake Ontario sites compared to other sites studied. The amount of PCBs in the eggs varied considerably throughout the lower Great Lakes, ranging from 0.02 µg/g at Algonquin Park (reference site) to 1.76 µg/g at Hamilton Harbour (Grindstone Creek).

The presence of non-native, invasive species can lead to degradation of coastal wetlands. For example, low water levels have resulted in the almost explosive expansion of reed canary grass (*Phalaris arundinacea*) in many wetlands, especially in Lake St. Clair and southern Lake Huron. Another disturbing trend 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. However, neither round goby nor the ruffe have been found in high densities in coastal wetlands anywhere in the Great Lakes. It seems likely that wetlands may be a refuge for native fishes, at least with respect to the influence of certain invasive fish species.

Many coastal and inland Great Lakes wetlands are at the lowest elevations in watersheds that support very intensive industrial, agricultural and residential development, and therefore are under pressure through polluted inflow received from their watersheds. Even more subtle impacts such as water level stabilization, sedimentation, contaminant and nutrient inputs, climate change, and invasion of non-native species continue to degrade wetlands across the Great Lakes region.

<u>Nearshore Terrestrial</u>: Mixed, Deteriorating/Undetermined
Great Lakes sand dunes comprise the world's largest collection of freshwater dunes. Approximately 131,546 ha of sand dunes can be found along the coasts of all the Great Lakes. Lake Michigan has the greatest number and area (111,291 ha), followed by Ontario (8,910 ha), Indiana (6,070 ha), New York (4,850 ha), and Wisconsin (425 ha). No comprehensive map of Great Lakes sand dunes exists, however. Cobble beaches comprise an estimated 1,640 km (1,019 miles) of the Great Lakes shoreline. This shoreline is decreasing, however, due to shoreline development. Alvar communities are naturally open habitats occurring on flat limestone bedrock. More than 90% of the world's alvars occur in the Great Lakes, and more than 90% of the original extent of alvar habitats has been destroyed or substantially degraded. Less than 20% of the nearshore alvar acreage is currently fully protected and 60% is at high risk. The Great Lakes contain the world's largest freshwater system of islands, which are globally significant in terms of their biological diversity. Nearshore island areas in the Ontario waters of Lake Huron account for 58% of the fish spawning and nursery habitat and are thus critically important to the Great Lakes fishery.

There is a continued loss of sand dunes to development, sand mining, recreational trampling, and non-native invasive species. Loss of sediment transport due to shoreline hardening is also a major pressure. Cobble beaches are most frequently threatened and lost by shoreline development. Homes and increased human activity are resulting in damage to rare plants and a loss of biodiversity. Continuing pressures on alvars include habitat fragmentation and loss, off-road vehicles, and resource extraction. Proposals to develop islands are increasing. In addition to development, island pressures include shoreline modification, non-native, invasive species, agriculture and forestry practices, and contamination.

A group of sand dune managers and scientists is organizing to convene a conference for all persons involved in Great Lakes sand dune ecosystem ecology, management, research and education efforts. The purposes of the conference will be to compile information about sand dunes and sand dune research and management and to form the Great Lakes Sand Dune Coalition. Not much research has been done on cobble beach communities; therefore, no baseline data has been set. A closer look into the percentage of cobble beaches that already have homes on them or are plotted for development would yield a more accurate trend. Protection of alvars has focused on best quality sites. Ten securement projects over the last several years have resulted in the protection of more than 5,000 acres across the Great Lakes basin. The Great Lakes Islands Collaborative will soon recommend management strategies on Great Lakes islands to preserve the unique ecological features that make islands to 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 islands areas. A suite of indicators that can be monitored to assess change, threats, and progress towards conservation of Great Lakes islands biodiversity is being developed by the Collaborative.

Acknowledgments

Karen Rodriguez, U.S. Environmental Protection Agency; and Ric Lawson, Great Lakes Commission.

COASTAL ZONES

ID #	Indicator Name	2005 Assessment (Status, Trend)
Nearshore Aquatic		
4861	Effect of Water Levels Fluctuations	Trend Not Assessed (2003 report)
8131	Extent of Hardened Shoreline	← (2001 report)
Coastal Wetlands		
4501	Coastal Wetland Invertebrate Community Health	Not Assessed
4502	Coastal Wetland Fish Community Health	Not Assessed
4504	Coastal Wetland Amphibian Diversity and Abundance	←
4506	Contaminants in Snapping Turtle Eggs	Trend Not Assessed
4507	Wetland-Dependent Bird Diversity and Abundance	←
4510	Coastal Wetland Area by Type	←
4861	Effect of Water Levels Fluctuations	Trend Not Assessed (2003 report)
4862	Coastal Wetland Plant Community Health	?
Terrestrial		
4861	Effect of Water Levels Fluctuations	Trend Not Assessed (2003 report)
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	Trend Not Assessed (2001 report)
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	←
8131	Extent of Hardened Shoreline	← (2001 report)

Status				Trend			
				→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Aquatic Habitats Assessment

Assessment
An overall assessment of this category has not been prepared. Included here is an assessment for the Groundwater sub-category.

State of the Ecosystem
Groundwater: *Mixed, Deteriorating*
Reports for four indicators to assess the state of groundwater resources in the Great Lakes watershed have been prepared: 1) Natural and Human-Induced Groundwater Quality, 2) Groundwater and Land Use and Intensity, 3) Base Flow Due to Groundwater Discharge, and 4) Groundwater-Dependent Plant and Animal Communities. Because these four groundwater indicators have only recently been developed, geographic coverage of entire Great Lakes watershed is currently available only for the indicator, *Base Flow Due to Groundwater Discharge*, and the authors of this report state that more analyses are needed to verify the conclusions of the report. Three indicator reports consider the Grand River watershed in Ontario as a case study. The authors of these reports caution that their conclusions may not apply to the entire Great Lakes watershed. In spite of these limitations, these four indicators, combined with other groundwater information in the Great Lakes, make a good case for an overall evaluation of groundwater resources in the Great Lakes to be *Mixed, Deteriorating*.

Natural and Human Induced Groundwater Quality. The quality of groundwater is particularly important when it is the source of drinking water, but quality is also a critical component for ecosystem function. Considerable progress has been achieved in reducing and cleaning up point sources of human-caused groundwater contamination. Non-point sources of contamination that effect groundwater quality have not been addressed as effectively. Because groundwater generally moves slowly from the time it is recharged until it is discharged, there may be a delay in the awareness of impaired groundwater quality. Similar conclusions about groundwater quality have been reached as a result of regional water-quality studies in the Lake Erie – Lake St. Clair watershed and in the western Lake Michigan watershed. The entire fresh groundwater resource in the Great Lakes region is underlain by naturally occurring saline groundwater and, therefore, simply drilling deeper wells is not a solution for most groundwater quality problems.

Groundwater and Land: Use and Intensity. Understanding the impact of water use on groundwater resources in the Great Lakes watershed will require a better understanding of how much water is available and how much is needed for maintaining healthy ecosystems and providing for sustained human uses. The conclusions for the Grand River watershed that more consistent and improved monitoring and data collection are needed to accurately estimate groundwater demand, as well as determine long-term trends in land use, are also accurate for nearly the entire Great Lakes watershed. Better analysis of the amount of groundwater that is consumptively used is an especially important need.

Base Flow Due to Groundwater Discharge. The discharge of groundwater to streams, wetlands, and lakes generally provides good quality water that, in turn, promotes habitat for aquatic plants and animals and that sustains them during periods of low precipitation. Human activities impact groundwater discharge by modifying the rates of discharge and the quality of the discharging water. The effects of urban development and agricultural practices are beginning to be documented by analysis of streamflow information. However, because of the slow movement of groundwater, the effects of surface activities and groundwater withdrawal on groundwater resources can sometimes take years to manifest themselves. Therefore, to better quantify the effects of human activities on this component of stream flow, we must continually update the current analyses and search for new ways to evaluate information about base flow.

Groundwater Dependant Plant and Animal Communities. The relationship between groundwater discharge to streams and aquatic habitat has long been noted but rarely quantified. As human activities increasingly cause changes in both the quantity and quality of groundwater discharging to streams, a better understanding of this relationship should be promoted. The indicator report for the Grand River watershed is an excellent example of how to promote this relationship. Similar work is being conducted in the United States as part of a Great Lakes Aquatic Gap Project. However, these are only the beginning steps in quantifying the effects of human activities on ecosystem function as it relates to groundwater discharge to streams.

Acknowledgments
Norman Grannemann, U.S. Geologic Survey.

AQUATIC HABITATS

ID #	Indicator Name	2005 Assessment (Status, Trend)
Open Lake		
111	Phosphorus Concentrations and Loadings	?
118	Toxic Chemical Concentrations in Offshore Waters	→
119	Concentrations of Contaminants in Sediment Cores	→
8131	Extent of Hardened Shoreline	← (2001 report)
Groundwater		
7100	Natural Groundwater Quality and Human-Induced Changes	Not Assessed
7101	Groundwater and Land: Use and Intensity	Not Assessed
7102	Base Flow Due to Groundwater Discharge	←
7103	Groundwater Dependant Plant and Animal Communities	Not Assessed

Status				Trend			
				→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Human Health Assessment

Assessment
Ecosystem Condition: Mixed
Ecosystem Trend: Generally Improving

State of the Ecosystem
The Great Lakes indicators for human health are generally improving. Due to the wide range of public health indicator topics, it is difficult to assign a specific ecosystem trajectory that is applicable to all topics. PCBs in fish continue to decline, biological markers of human exposure are better assessed, progress is being made in reducing air pollution, beaches are better assessed and more frequently monitored, and drinking water quality continues to be good.

Assessment of human health through indicators has improved over the past 20 years. However, a greater understanding of human health and environmental interaction is needed. For example, complex issues that warrant more research are associated with the relationship between environmental exposures and biological makers in humans, and with beach advisories, postings and closures. Efforts to understand and resolve these issues should be continued and enhanced.

Contaminants in Sport Fish. Since the 1970's there have been declines in many persistent bioaccumulative toxic (PBT) chemicals in the Great Lakes basin. One such chemical, PCBs, is analyzed in coho salmon to better understand potential human exposure and general, temporal trends. While the data show that concentrations of the contaminants are generally decreasing, other contaminants, such as mercury and PBDE, will need to be better understood through improved monitoring and risk analysis. State, Tribe, and Federal fish consumption advisories are important for protecting the public, especially sensitive populations, from exposure to contaminants in fish. Enhanced partnerships between the parties involved in issuing advisories will improve both commercial and sport fish consumption advisory programs.

Air Quality. Overall, there has been significant progress in reducing air pollution in the Great Lakes basin. In general there has been a reduction of urban/local pollutants over the past decade, although there are a few remaining problems districts. Regional pollutants such as ground-level ozone and fine particulates remain a concern in the Great Lakes basin, 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. Continuing health research is both broadening the number of identified toxins and producing evidence that existing standards should be lowered.

Biological Markers of Human Exposure to Persistent Chemicals. There are several studies underway in the Great Lakes basin evaluating the connection between fish consumption and chemical exposure. Some of these studies go further and evaluate the potential of harmful health effects from chemical exposure. Two studies were evaluated as part of this indicator. The first study, completed by Wisconsin Department of Health and Family Services, analyzed the level of bioaccumulative toxic chemicals found in sensitive populations in the Great Lakes basin. Based on this analysis, it appears that there is a correlation between hair mercury levels and the number of fish meals consumed over three months. In the EAGLE Project (Effects on Aboriginals of the Great Lakes), the effects of contaminants on the health of the Great Lakes aboriginal population was examined and results of this study indicated that contaminant levels were found to be below or within the range of other Canadian health Studies completed in the Great Lakes basin. The Agency for Toxic Substances and Disease Registry (ATSDR) established the Great Lakes Human Health Effects Research Program through legislative mandate in 1992. This program is tasked with assessing critical pollutants of concern, identifying vulnerable and sensitive populations, prioritizing areas of research and funding research projects within the Great Lakes. Many of their research projects are highlighted in the indicator report.

Beach Advisories, Postings and Closures. Bacterial count in nearshore water is one of the most important indicators to determine if health-related closings, postings and advisories at beaches are needed. Recreational waters may become contaminated with animal and human feces from sources and conditions such as combined sewer overflows (CSO) and sanitary sewer overflows (SSO), malfunctioning septic systems and poor live stock management practices. States, tribes and provinces are continuing to identify and improve remediation measurers to reduce the number of closings, postings and advisories at beaches. Trends in the U.S. and Canada show that as the frequency of monitoring and reporting increase, more advisories, posting and closures are observed. Data collectors at some beaches in the basin are using their monitoring data, meteorological data, other information, and computer modeling to better forecast beach closures.

Drinking Water Quality. There are several Great Lakes basin sources for tap water including lakes, rivers, streams, ponds, reservoirs, springs, and wells. Water traveling over the surface of the land or through the ground is vulnerable to contamination by naturally occurring minerals, substances resulting from animals or anthropogenic activity, and in some instances, radioactive material. U.S. and Canadian finished water and Canadian raw water that was evaluated for this report originated from many water sources, including Lake Erie, Lake Huron, Lake Michigan (U.S. only), Lake Ontario, Lake Superior, rivers, small lakes/reservoirs, and groundwater. Ten drinking water parameters were chosen to provide the best pictures of drinking water quality in the Great Lakes basin, including several chemical parameters, microbiological parameters, and other indicators of potential health hazards.

The quality of finished drinking water in the Great Lakes basin is good based on the information provided by the Ontario Ministry of the Environment and data collected as part of the Canadian Drinking Water Surveillance Program, in addition to information gathered from 2002 and 2003 U.S. Consumer Confidence / Water Quality Reports. The information provided helps to demonstrate that both the U.S. and Canadian Water Treatment Plants are employing treatment technologies that successfully treat water, thus enabling them to provide quality drinking water. Few, if any, violations of federally regulated standards were reported, supporting the claim that drinking water quality is good. The risk of human exposure to a noted chemical and/or microbiological contaminants in drinking water is generally low. Therefore, the potential for humans to develop health complications as a result of consuming drinking water containing these contaminants from the Great Lakes basin is also low.

Acknowledgments
Jacqueline Fisher and Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office.

HUMAN HEALTH

ID #	Indicator Name	2005 Assessment (Status, Trend)
4175	Drinking Water Quality	◆
4177	Biologic Markers of Human Exposure to Persistent Chemicals	?
4200	Beach Advisories, Postings and Closures	?
4201	Contaminants in Sport Fish	→
4202	Air Quality	→

Status				Trend			
				→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Land Use - Land Cover Assessment

The overall assessment for this category of indicators is not available at this time.

LAND USE - LAND COVER

ID #	Indicator Name	2005 Assessment (Status, Trend)
General		
7002	Land Cover / Land Conversion	Not Assessed
7101	Groundwater and Land: Use and Intensity	Not Assessed
Forest Lands		
8500	Forest Lands - Conservation of Biological Diversity	→
Agricultural Lands		
7028	Sustainable Agriculture Practices	Not Assessed
7061	Nutrient Management Plans	Not Assessed
7062	Integrated Pest Management	Not Assessed
Urban/Suburban Lands		
7000	Urban Density	Trend Not Assessed
7006	Brownfield Redevelopment	→ (2003 report)
Protected Areas		
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	Trend Not Assessed (2001 report)
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	←

Status				Trend			
				→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Resource Utilization Assessment

The overall assessment for this category of indicators is not available at this time.

RESOURCE UTILIZATION

ID #	Indicator Name	2005 Assessment (Status, Trend)
3514	Commercial/Industrial Eco-Efficiency Measures	Not Assessed (2003 report)
7043	Economic Prosperity	For Lake Superior Basin Trend Not Assessed (2003 report)
7056	Water Withdrawals	◆
7057	Energy Consumption	Trend Not Assessed
7060	Solid Waste Generation	Trend Not Assessed (2003 report)

Status				Trend			
				→	◆	←	?
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Climate Change Assessment

The overall assessment for this category of indicators is not available at this time.

CLIMATE CHANGE

ID #	Indicator Name	2005 Assessment (Status, Trend)
4858	Climate Change: Ice Duration on the Great Lakes	Mixed, Deteriorating (2003 report)

Status				Trend			
Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

4.2 Indicator Reports and Assessments

The following indicator reports have been arranged in numerical order using the indicator I.D. number in order to facilitate the rapid location of any indicator report by the reader.

Salmon and Trout

Indicator #8

Assessment: **Mixed, Improving**

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 true salmon and trout species
Salmonid	Refers to any species of fish with an adipose fin, including trout, salmon, whitefish, grayling, 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 848 million non-native salmonines were stocked in the Great Lakes basin between 1966 and 2001. 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.

Data are available for the total number of non-native salmonines

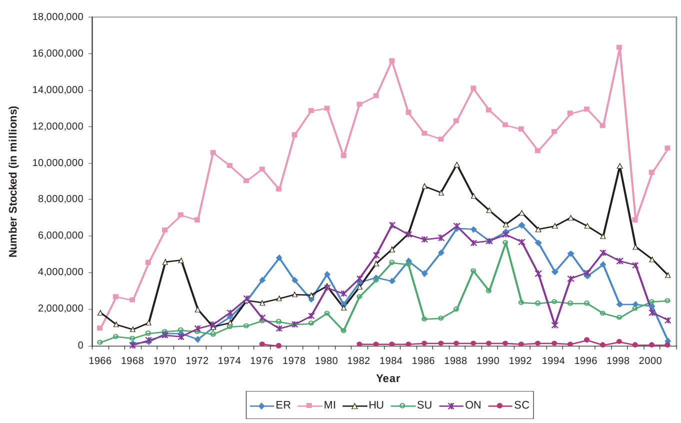

Figure 1. Total number of non-native salmonines stocked in the Great Lakes, 1966-2001 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking)

stocked in each of the Great Lakes from 1966-2001 (Figure 1). 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 Ontario, Huron and Erie all seem to display a similar overall downward trend in stocking, especially in recent years. Since the late 1980s, the number of non-native salmonines stocked in the Great Lakes has been nearly constant or slightly

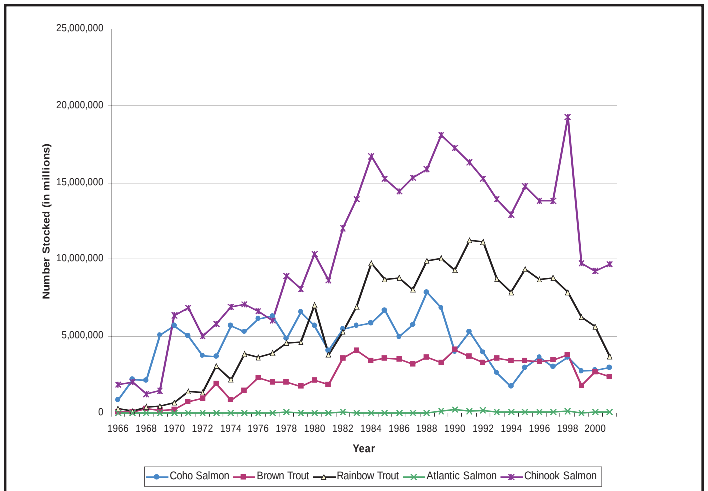

Figure 2. Non-Native salmonine stocking by species in the Great Lakes, 1966-2001 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking)

declining with the exception of a 1998 peak in Lakes Michigan and Huron. 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). Of non-native salmonines, chinook salmon are the most heavily stocked, accounting for about 45% of all non-native salmonine releases (Figure 2). 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).

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 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.

Acknowledgments

Author: Erin Clark, Environment Canada, Downsview, ON.
Special thanks to 2003 report author: Melissa Greenwood, Environment Canada, Downsview, ON.

Sources

Bowlby, J.N., and Daniels, M.E. 2002. *Lake Ontario Pelagic Fish 2: Salmon and Trout.* 2002 Annual Report. www.glfc.org/lakecom/loc/mgmt_unit/index.html, last accessed May 14, 2004.

Brown, E.H., Jr., Busiahn, T.R., Jones, M.L., and Argyle, R.L. 1999. Allocating Great Lakes Forage Bases in Response to Multiple Demand. In *Great Lakes Fisheries Policy and Management: a Binational Perspective*, eds. W.W. Taylor and C.P. Ferreri, pp. 355-394. East Lansing, MI: Michigan State University Press.

Crawford, S.S. 2001. *Salmonine Introductions to the Laurentian Great Lakes: An Historical Review and Evaluation of Ecological Effects*. Canadian Special Publication of Fisheries and Aquatic Sciences. pp. 132-205.

Great Lakes Fishery Commission (GLFC). 2001. *Strategic Vision of the Great Lakes Fishery Commission for the First Decade of the New Millennium.* http://www.glfc.org, last accessed April 30, 2004.

Great Lakes Fishery Commission (GLFC). 1997. *A Joint Strategic Plan for Management of Great Lakes Fisheries.* http://www.glfc.org/fishmgmt/sglfmp97.htm, last accessed April 28, 2004.

Hansen, M.J., and Holey, M.E. 2002. Ecological factors affecting the sustainability of chinook and coho salmon populations in the Great Lakes, especially Lake Michigan. In *Sustaining North American salmon: Perspectives across regions and discipline*, eds. K.D. Lynch, M.L. Jones and W.W. Taylor, pp.155-179. Bethesda, MD: American Fisheries Society Press.

Indiana Division of Fish and Wildlife, Great Lakes Sport Fishing Council. 1997. *Alewife Die-Offs Expected on Indiana Shores.* http://www.great-lakes.org/5-05-97.html, last accessed May 4, 2004.

Kocik, J.F., and Jones, M.L. 1999. Pacific Salmonines in the Great Lakes Basin. In *Great Lakes Fisheries Policy and Management: a Binational Perspective*, eds. W.W. Taylor and C.P. Ferreri, pp. 455-489. East Lansing, MI, Michigan State University Press.

Rand, P.S., and Stewart, D.J. 1998. Prey fish exploitation, salmonine production, and pelagic food web efficiency in Lake Ontario. *Can. J. Fish. Aquat. Sci.* 55(2):318-327.

Schaner, T., Bowlby, J.N., Daniels, M., and Lantry, B.F. 2001. *Lake Ontario Offshore Pelagic Fish Community*. Lake Ontario Fish Communities and Fisheries: 2000 Annual Report of the Lake Ontario Management Unit.

Authors' Commentary

This indicator should be reported frequently as salmonine stocking is a complex and dynamic management intervention in the Great Lakes ecosystem.

Walleye

Indicator #9

Assessment: Good, Unchanging

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 2003 in most areas (Figure 1). Total yields were highest in Lake Erie (annual average of about 4,600 metric tons, 1975-2003), intermediate in Lakes Huron and Ontario (<300 metric tons in all years), and lowest in Lakes Michigan and Superior (<10 metric tons). Declines after the mid-1990s were likely related to shifts in environmental states (i.e., from mesotrophic to less favorable oligotrophic conditions), less frequent production of strong hatches, and changing fisheries. The effects of non-native species on the food web or on walleye behaviour (increased water clarity can limit daytime feeding) also may have been a contributing factor. In general, walleye yields peaked under ideal environmental conditions and declined under less favorable (i.e., non-mesotrophic) conditions. Despite recent declines in walleye yields, environmental conditions remain improved relative to the 1970s.

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. Moreover, alterations in the food web can affect environmental characteristics (like water clarity), which can in turn affect fish behaviour and fishery yields.

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). 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 fisheries management, which is 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.

Acknowledgments

Author: Roger Knight, Ohio Department of Natural Resources.

Sources

Fishery harvest data were obtained from the following sources:
Lake Superior:
Ken Cullis, Ontario Ministry of Natural Resources,
ken.cullis@mnr.gov.on.ca

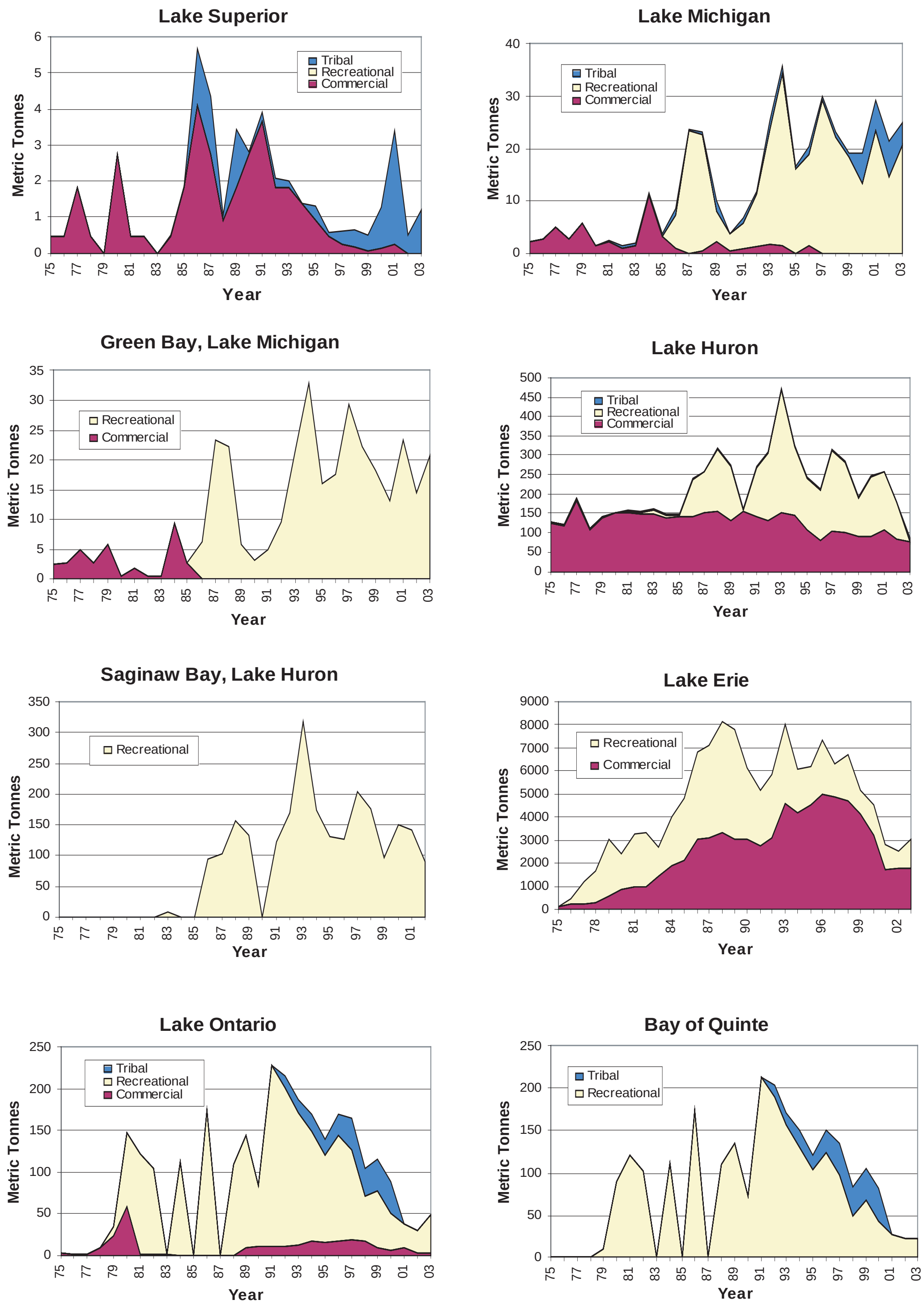

Figure 1. Recreational, commercial and tribal harvest of walleye from the Great Lakes. Fish Community Goals and Objectives are: Lake Michigan, 100-200 metric tons; Lake Huron, 700 metric tons; Lake Erie, sustainable harvest in all basins.
Source: Ontario Ministry of Natural Resources, Chippewa Ottawa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

Lake Michigan:
Karen Wright, Chippewa Ottawa Resource Authority, kwright@sault.com
Kevin Kapuscinski, Wisconsin Department of Natural Resources, kevin.kapuscinski@dnr.state.wi.us

Lake Huron:
Dave Fielder, Michigan Department of Natural Resources, fielderd@state.mi.us
Lloyd Mohr, Ontario Ministry of Natural Resources, lloyd.mohr@mnr.gov.on.ca

Lake Erie:
Brian Locke, Ontario Ministry of Natural Resources, brian.locke@mnr.gov.on.ca
Roger Knight, Ohio Department of Natural Resources, roger.knight@dnr.state.oh.us

Lake Ontario:
Jim Hoyle, Ontario Ministry of Natural Resources, jim.hoyle@mnr.gov.on.ca
Steve Lapan, New York Department of Environmental Conservation, srlapan@gw.dec.state.ny.us

Also consulted were various annual Lake Erie fisheries reports from Ontario Ministry of Natural Resources and Ohio Department of Natural Resources, and the Great Lakes Fishery Commission commercial fishery database.

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

Authors' Commentary
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. 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 and encourage all agencies to compile walleye harvest data from their major fisheries. In light of serious fiscal constraints now being imposed on virtually all agencies, this recommendation will be difficult to achieve. Alternatively, 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.

Preyfish Populations

Indicator #17

Assessment: Mixed, Deteriorating (Lakes Michigan, Huron, Erie, Ontario)
Mixed, Improving (Lake Superior)

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 forage fish populations. In addition, the bloater and the lake herring, which are native species, and the rainbow smelt 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 thompsoni*), and to a lesser degree species like lake whitefish (*Coregonus clupeaformis*), ninespine stickleback (*Pungitius pungitius*) and slimy sculpin (*Cottus cognatus*) constitute the bulk of the preyfish communities (Figure 1).

In Lake Erie, the prey fish community is unique among the Great Lakes in that it is characterized by relatively high species diversity. The prey fish 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 (*Neogobius melanostomus*), 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 alewives, and to a lesser degree rainbow smelt, dominate the prey fishes. The alewife population remains at a level well below that of the early 1980s. Rainbow smelt declined to a new low, well below that of the previous record low, and have an abbreviated age and size structure that suggests the population is under heavy predation pressure. Abundance of slimy sculpins along the south shore at depths >70 m remain well below the 1991 peak and is unlikely to recover in the absence of *Diporeia*. No deepwater sculpins were collected in 2001-2003.

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, although slight increases have occurred in the past couple years. 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 forage fish abundance associated with declines in abundance of age-0 white perch and rainbow smelt. The clupeid component of the forage fish community has shown no overall trend in the past decade, although gizzard shad and alewife abundance has been quite variable across the survey period, and in 2003 declined to the low levels observed in 1998.

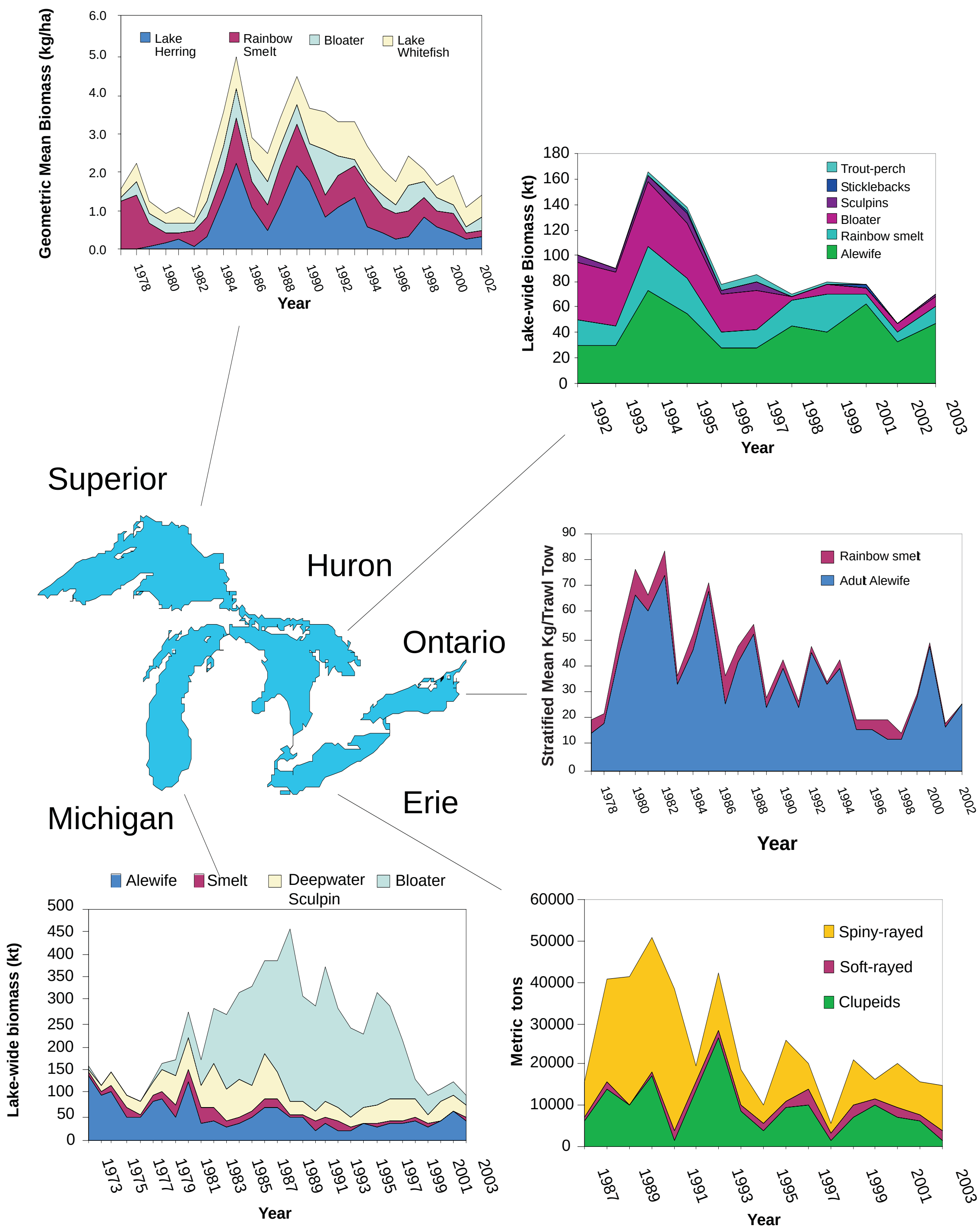

Figure 1. Preyfish trends based on annual bottom trawl surveys. All trawl surveys were performed by USGS - Great Lakes Science Center, except for Lake Erie, which was conducted by the Ohio Division of Wildlife and the Ontario Ministry of Natural Resources.
Source: U.S. Geological Survey - Great Lakes Science Center, Ohio Division of Wildlife, and Ontario Ministry of Natural Resources

The biomass estimates for western Lake Erie were based on data from bottom trawl catches, data from acoustic trawl mensuration gear, and depth strata extrapolations (0-6 m, and >6 m).

Lake Michigan: *Mixed, deteriorating*
In recent years, alewife biomass has remained at consistently lower levels compared to the 1970s-1980s. Some increase in abundance is noted with strong 1995 and 1998 year classes, but the current low population levels appear to be driven in large part by predation pressure. Rainbow smelt have declined and remain at lower levels, possibly due to predation. The decline in bloater biomass after 1990 has been attributed to a lack of recruitment and slow growth. Since 2000 bloater has declined more slowly, and may rebound as part of an anticipated natural cycle in abundance. Deepwater sculpins remain at the same level of abundance and continue to contribute a significant portion of the preyfish biomass. Yellow perch year-class strength was poor in 2003, indicating another in a series of failed year classes since 1989. Lake-wide biomass of Dreissenid mussels increased from 14 kt to 43 kt between 1999 and 2001 but afterwards decreased sharply, reaching 14 kt in 2003 (with the quagga mussel invasion well underway) while *Diporeia* populations continue to decline. The first catch of round gobies appeared in our annual lake-wide survey in 2003.

Lake Huron: *Mixed, deteriorating*
The fish community of Lake Huron during 2003 was very different from recent years. Adult alewife abundance during 2003 was extremely low, presumably due to a combination of over-winter mortality during 2002-2003 and salmonid predation. However, age-0 alewives were more abundant than at any time since 1992 due to an exceptionally strong year class. Adult rainbow smelt abundance was the lowest observed since 1992, but age-0 rainbow smelt were abundant, indicating a potentially strong year class. Adult bloater abundance increased slightly from 2002, but age-0 bloaters were ubiquitous. The CPE (catch per effort) of juvenile bloaters was the highest recorded since 1992, and the 2003 year class may be one of the largest since annual surveys began in 1973. Abundances for most other prey species were stable, but round gobies continued to increase at southern ports. Prey biomass available to the trawl increased during 2003 with alewives comprising the bulk of the biomass. However, unlike in 2002, alewife biomass was composed almost entirely of age-0 fish rather than adults. Predators in Lake Huron face potential prey shortages. Although overall prey density was high, there were few adult alewives or rainbow smelt available. Predator feeding conditions during 2004 will depend on over-winter survival of age-0 alewife and the ability of large predators to subsist on small or non-traditional prey. Overall, the Lake Huron fish community is dominated by non-native species, notably alewife. Round gobies and Dreissenid mussels are proliferating throughout the lake and increasing in abundance.

Lake Superior: *Mixed, improving*
Over the past 10-15 years, prey fish populations declined in total biomass when compared to the peak years in 1986, 1990, and 1994, a period when lake herring was the dominant prey fish species and wild lake trout populations were starting to recover. Since the early 1980s, dynamics in the total biomass of preyfish have been driven largely by variation in recruitment of age-1 lake herring. Strong year classes in 1984, 1989, and 1998 were largely responsible for peak lake herring biomass in 1986, 1990-1994, and 1999. Recent survey data now suggest that a strong year class was produced in 2003. During 1978-1984, rainbow smelt was the dominant prey fish, but it has subsequently declined to a lower but relatively constant level during the 1984-2001 interval. During the recent 2002-2003 interval, rainbow smelt biomass declined to the lowest levels in the time series. There is strong evidence that declines in smelt biomass are tied to increased predation by recovered lake trout populations. Biomass of bloater and whitefish has increased since the early 1980s, and biomass for both species has been more constant than lake herring. The rise and fall of total prey fish biomass over 1984-2003 reflects the recovery of wild lake trout stocks and resumption of commercial harvest of lake herring in Lake Superior. Increases in prey fish populations are not likely without reductions in harvest by predators and commercial fisherman. Other species, notably sculpins, burbot, and 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 fish community appears to be largely the result of the recovery of wild lake trout stocks coupled with the resumption of human harvest of key prey species.

Pressures
The influences of predation by salmon and trout on preyfish populations appear to be common across all lakes. Additional pressures from *Dreissena* populations are apparent in Lakes Ontario, Erie and Michigan. Bottom-up effects on the prey fishes have already been observed in Lake Ontario following the Dreissenid-linked collapse of *Diporeia*, and they are likely to become apparent in Lakes Michigan and Huron as Dreissenids expand and *Diporeia* decline. Furthermore, anecdotal observations in Lake Ontario indicate that *Mysis* are declining as Dreissenids proliferate in profundal waters, suggesting that dynamics of prey fish populations in future years could be driven by bottom-up rather than top-down effects in Lakes Michigan, Huron and Ontario.

Management Implications
Recognition of significant predation effects on preyfish populations has resulted in recent salmon stocking cutbacks in Lakes Michigan, Huron and Ontario. However, even with a reduced population, alewives have exhibited the ability to produce strong year classes 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 since lake trout and salmon are almost entirely lake-produced. Potential bottom-up effects on prey fishes 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.

Acknowledgments

Author: Owen T. Gorman, U.S. Geological Survey, Great Lakes Science Center, Lake Superior Biological Station, Ashland, WI.

Contributors: Robert O'Gorman and Randy W. Owens, U.S. Geological Survey (USGS) Great Lakes Science Center, Lake Ontario Biological Station, Oswego, NY;
Charles Madenjian and Jeff Schaeffer, USGS Great Lakes Science Center, Ann Arbor, MI;
Mike Bur, USGS Great Lakes Science Center, Lake Erie Biological Station, Sandusky, OH; and
Jeffrey Tyson, Ohio Division of Wildlife, Sandusky Fish Research Unit, Sandusky, OH.

Authors' Commentary

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 prey fishes 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 prey fishes, most notably the various members of the whitefish family (*Coregonus* spp.), should be a priority in all the Great Lakes. This recommendation would include the deepwater cisco species and 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 prey fishes, the appropriate frequency to review this indicator is on a 5-year basis.

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

Background

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.

Status of Sea Lamprey

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.

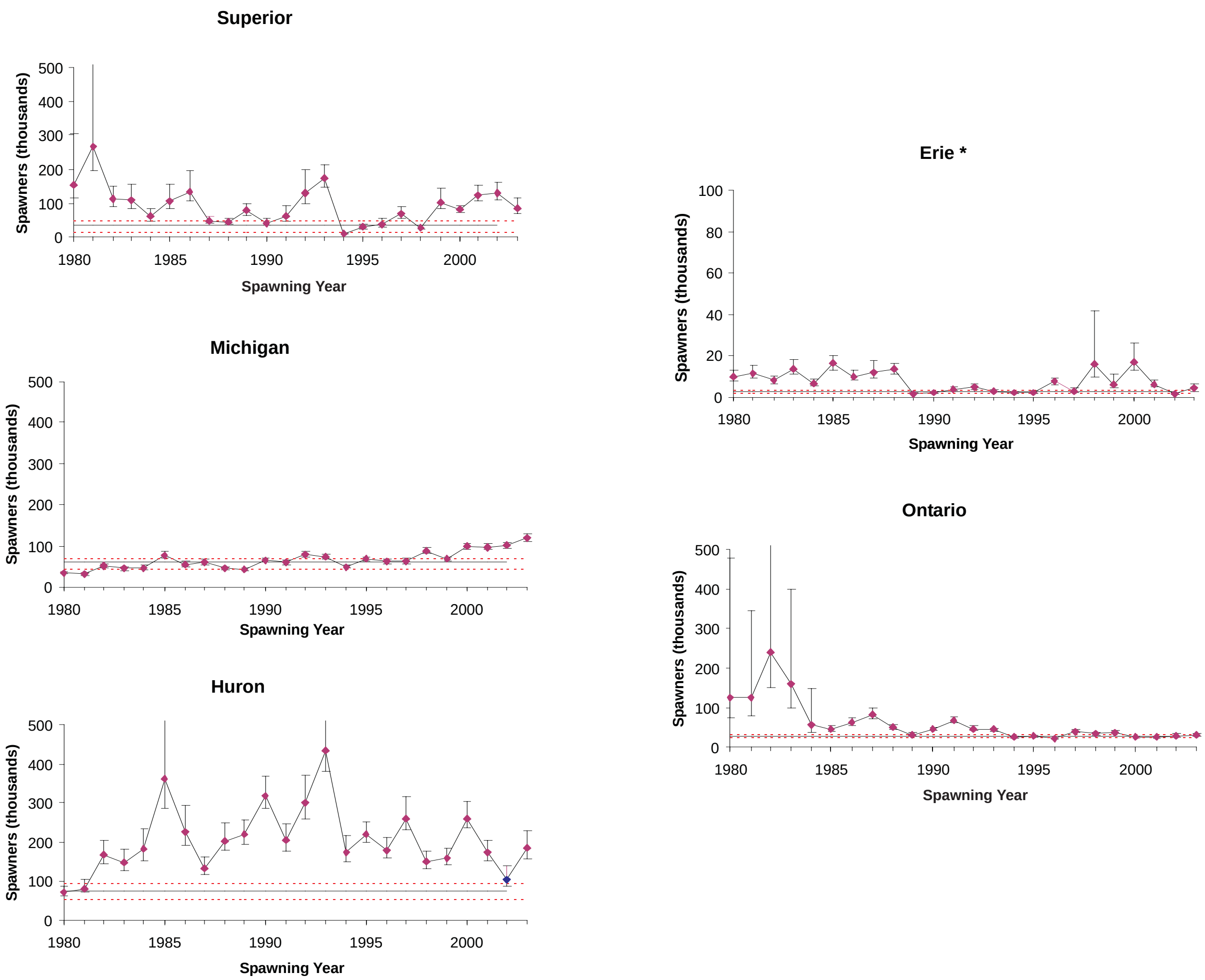

Figure 1. Total abundance of sea lampreys estimated during the spawning migration. Solid line and dashed line represent FCO target abundance and ranges, respectively.
*Note: the scale for Lake Erie is 1/5 that of the other four Lakes.
Source: Great Lakes Fishery Commission

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.

Sources

Adams, J.V., Bergstedt, R.A., Christie, G.C., Cuddy, D.W., Fodale, M.F., Heinrich, J.W., Jones, M.L., McDonald, R.B., Mullett, K.M., and Young, R.J. 2003. Assessing assessment: can we detect the expected effects of the St. Marys River sea lamprey control strategy? *J. Great Lakes Res.* 29 (Suppl. 1):717-727.

DesJardine, R.L., Gorenflo, T.K., Payne, R.N., and Schrouder, J.D. 1995. *Fish-community objectives for Lake Huron.* Great Lakes Fish. Comm. Spec. Publ. 95-1.

Eshenroder, R.L., Holey, M.E., Gorenflo, T.K., and Clark, R.D., Jr. 1995. *Fish-community objectives for Lake Michigan*. Great Lakes Fish. Comm. Spec. Publ. 95-3.

Great Lakes Fishery Commission (GLFC). 1955. Convention on Great Lakes Fisheries, Ann Arbor, MI.

Heinrich, J.W., Mullett, K.M, Hansen, M.J., Adams, J.V., Klar, G.T., Johnson, D.A., Christie, G.C., and Young, R.J. 2003. Sea lamprey abundance and management in Lake Superior, 1957-1999. *J. Great Lakes Res.* 29 (Suppl. 1):566-583.

Horns, W.H., Bronte, C.R., Busiahn, T.R., Ebener, M.P., Eshenroder, R.L., Greenfly, T., Kmiecik, N., Mattes, W., Peck, J.W., Petzold, M., and Schneider, D.R. 2003. *Fish-community objectives for Lake Superior*. Great Lakes Fish. Comm. Spec. Publ. 03-01.

Larson, G.L., Christie, G.C., Johnson, D.A., Koonce, J.F., Mullett, K.M., and Sullivan, W.P. 2003. The history of sea lamprey control in Lake Ontario and updated estimates of suppression targets. *J. Great Lakes Res.* 29 (Suppl. 1):637-654.

Lavis, D.S., Hallett, A., Koon, E.M., and McAuley, T. 2003. History of and advances in barriers as an alternative method to suppress sea lampreys in the Great Lakes. *J. Great Lakes Res.* 29 (Suppl. 1):584-598.

Morse, T.J., Ebener, M.P., Koon, E.M., Morkert, S.B., Johnson, D.A., Cuddy, D.W., Weisser, J.W., Mullet, K.M., and Genovese, J.H. 2003. A case history of sea lamprey control in Lake Huron: 1979-1999. *J. Great Lakes Res.* 29 (Suppl. 1):599-614.

Mullett, K M., Heinrich, J.W., Adams, J.V. Young, R. J., Henson, M.P., McDonald, R.B., and Fodale, M.F. 2003. Estimating lake-wide abundance of spawning-phase sea lampreys (*Petromyzon marinus*) in the Great Lakes: extrapolating from sampled streams using regression models. *J. Great Lakes Res.* 29 (Suppl. 1):240-253.

Ryan, P.S., Knight, R., MacGregor, R., Towns, G., Hoopes, R., and Culligan, W. 2003. *Fish-community goals and objectives for Lake Erie.* Great Lakes Fish. Comm. Spec. Publ. 03-02.

Schleen, L.P., Christie, G.C., Heinrich, J.W., Bergstedt, R.A., Young, R.J., Morse, T.J., Lavis, D.S., Bills, T.D., Johnson J., and Ebener, M.P. 2003. *In press*. Development and implementation of an integrated program for control of sea lampreys in the St. Marys River. *J. Great Lakes Res.* 29 (Suppl. 1):677-693.

Stewart, T.J., Lange, R.E., Orsatti, S.D., Schneider, C.P., Mathers, A., and Daniels M.E. 1999. *Fish-community objectives for Lake Ontario*. Great Lakes Fish. Comm. Spec. Publ. 99-1.

Sullivan, W.P., Christie, G.C., Cornelius, F.C., Fodale, M.F., Johnson, D.A., Koonce, J.F., Larson, G.L., McDonald, R.B., Mullet, K.M., Murray, C.K., and Ryan, P.A. 2003. The sea lamprey in Lake Erie: a case history. *J. Great Lakes Res.* 29 (Suppl. 1):615-637.

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.

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

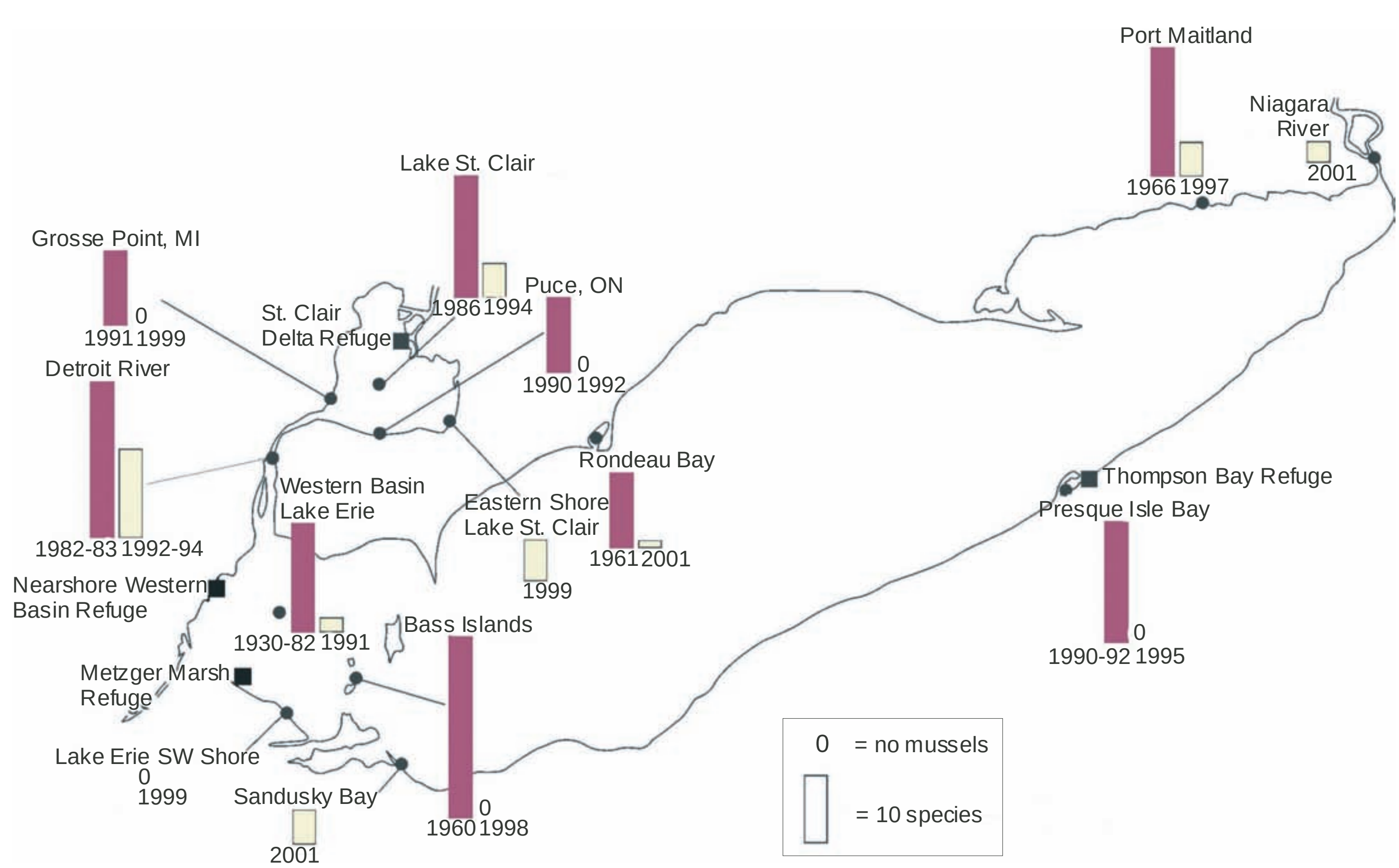

Figure 1. Numbers of freshwater mussel species found before and after the zebra mussel invasion at 13 sites in Lake Erie, Lake St. Clair, and the Niagara and Detroit Rivers (no "before" data available for 4 sites), and the locations of the four known refuge sites (Thompson Bay, Metzger Marsh, Nearshore 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
Authors: Janice L. Smith, Biologist, Aquatic Ecosystem Impacts Research Branch, National Water Research Institute, Burlington, ON, Janice.Smith@ec.gc.ca; and
S. Jerrine Nichols, U.S. Geological Survey, Biological Resources Division, Ann Arbor, MI, s_jerrine_nichols@usgs.gov.

Sources
Bowers, R., and De Szalay, F. 2003. Effects of hydrology on unionids *(Unionidae)* and zebra mussels *(Dreissenidae)* in a Lake Erie coastal wetland. *American Midland Naturalist* 151:286-300.

Martel, A.L., Pathy, D.A., Madill, J.B., Renaud, C.B., Dean, S.L., and Kerr, S.J. 2001. Decline and regional extirpation of freshwater mussels *(Unionidae)* in a small river system invaded by *Dreissena polymorpha*: the Rideau River, 1993-2000. *Can. J. Zool.* 79(12):2181-2191.

Metcalfe-Smith, J.L., Zanatta, D.T., Masteller, E.C., Dunn, H.L., Nichols, S.J., Marangelo, P.J., and Schloesser, D.W. 2002. *Some* *nearshore areas in Lake Erie and Lake St. Clair provide refuge for native freshwater mussels* (Unionidae) *from the impacts of invading zebra and quagga mussels* (Dreissena). Presented at the 45th Conference on Great Lakes Research, June 2-6, 2002, Winnipeg, MB, abstract on p.87 of program.

Nichols, S.J., and Amberg, J. 1999. Co-existence of zebra mussels and freshwater unionids; population dynamics of *Leptodea fragilis* in a coastal wetland infested with zebra mussels. *Can. J. Zool.* 77(3):423-432.

Nichols, S.J., and Wilcox, D.A. 1997. Burrowing saves Lake Erie clams. *Nature* 389:921.

Schloesser, D.W., Smithee, R.D., Longdon, G.D., and Kovalak, W.P. 1997. Zebra mussel induced mortality of unionids in firm substrata of western Lake Erie and a habitat for survival. *American Malacological Bulletin* 14:67-74.

Strayer, D.L., and Smith, D.R. 2003. *A guide to sampling freshwater mussel populations.* American Fisheries Society, Monograph 8, Bethesda, MD. 103 pp.

The National Native Mussel Conservation Committee. 1998. National strategy for the conservation of native freshwater mussels. *J. Shellfish Res.* 17(5):1419-1428.

Zanatta, D.T., Mackie, G.L., Metcalfe-Smith, J.L., and Woolnough, D.A. 2002. A refuge for native freshwater mussels *(Bivalvia: Unionidae)* from impacts of the non-native zebra mussel *(Dreissena polymorpha)* in Lake St. Clair. *J. Great Lakes Res.* 28(3):479- 489.

Lake Trout

Indicator #93

Assessment: Mixed, Improving (Lakes Superior, Huron)
Mixed, Unchanging (Lakes Michigan, Erie, Ontario)

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 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 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 the Great Lakes Lake 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 largely discontinued. Sustained natural reproduction, albeit at low levels, has also been occurring in Lake Ontario since the early 1990s, and in isolated areas of Lake Huron, but has been largely absent elsewhere in the Great Lakes. Parental stock sizes of hatchery-reared fish are relatively high in Lake Ontario and southern Lake Huron and in a few areas of Lake 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 northern Lake Huron and in Lake Michigan. 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 and moderate fishing mortality; hence egg deposition is low in most historically important spawning areas. High biomass of alewives and predators on lake

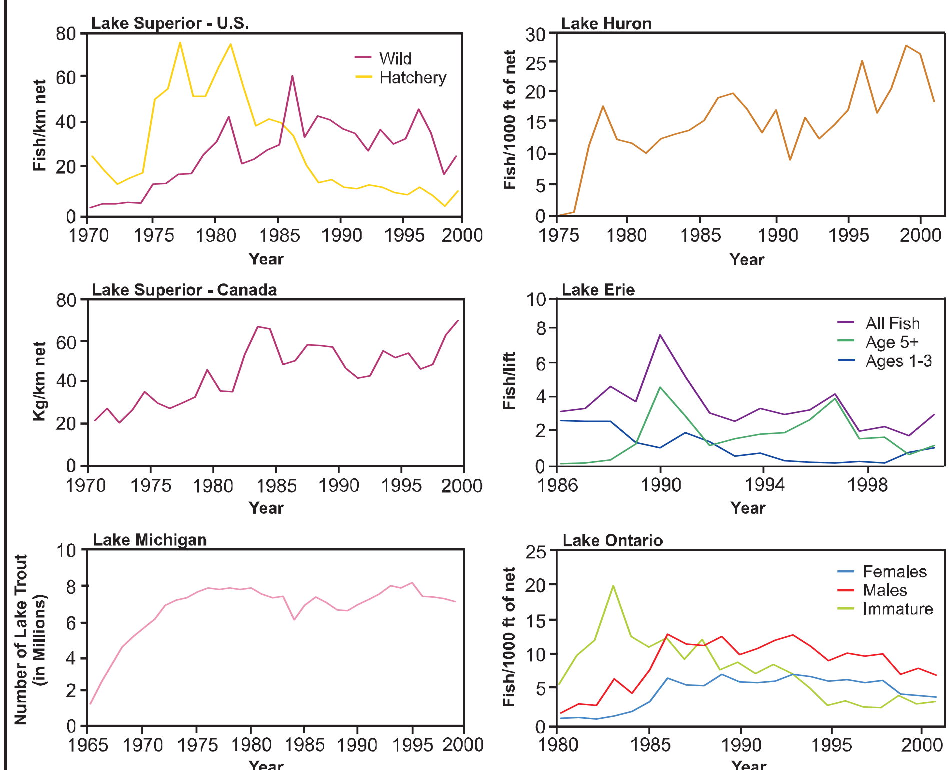

Figure 1: Relative or absolute abundance of lake trout in the Great Lakes. The measurement reported varies from lake to lake, as shown on the vertical scale, and comparisons between lakes may be misleading. Overall trends over time provide information on relative abundances.
Source: U.S. Fish and Wildlife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

trout spawning reefs are thought to inhibit restoration through egg and fry predation, although the magnitude of this pressure is unclear. 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 sea lamprey control, especially on the St. Marys River and in northern Lake Michigan tributaries, is required 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 modelling 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, and 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. The relationship between early mortality syndrome and alewives as prey needs to be further investigated to account for inconsistent experimental and empirical results. Direct stocking of eggs, fry, and yearling on or near traditional spawning sites should be used where possible to enhance colonization.

Acknowledgments

Authors: Charles R. Bronte, U.S. Fish and Wildlife Service, Green Bay, 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.

Sources

Bence, J.R., and Ebener, M.P. (eds.). 2002. *Summary status of lake trout and lake whitefish populations in 1936 treaty-ceded waters of Lakes Superior, Huron and Michigan in 2000, with recommended yield and effort levels for 2001.* Technical Fisheries Committee, 1836 Treaty-Ceded Waters of Lakes Superior, Huron and Michigan.

Bronte, C.R., Ebener, M.P., Schreiner, D.R., DeVault, D.S., Petzold, M.M., Jensen, D.A., Richards, C., and Lozano, S.J. 2003a. Fish community change in Lake Superior, 1970-2000. *Can. J. Fish. Aquat. Sci.* 60:1552-1574.

Bronte, C.R. Holey, M.E., Breidert, B., Claramunt, R.M., Jonas, J., Ebener, M.P., Fleischer, G.W., Madenjian, C.P., Hess, H., Martell, A., Olsen, E.J., McKee, P., and Toneys, M.L. 2003b. *Success of current strategies to re-colonize lake trout spawning reefs in northern Lake Michigan.* Final report, Project 1999.6, Great Lakes Fishery Trust.

Bronte, C.R., Jonas, J., Holey, M.E., Eshenroder, R.L., Toneys, M.L., McKee, P., Breidert, B., Claramunt, R.M., Ebener, M.P., Krueger, C.C., Wright, G., and Hess, R. 2003c. *Possible impediments to lake trout restoration in Lake Michigan.* Lake Trout Task Group report to the Lake Michigan Committee, Great Lakes Fishery Commission.

Bronte, C.R., Schram, S.T., Selgeby, J.H., and Swanson, B.L. 2002. Reestablishing a spawning population of lake trout in Lake Superior with fertilized eggs in artificial turf incubators. *N. Am. J. Fish. Manage.* 22:796- 805.

Cornelius, F.C., Muth, K.M., and Kenyon, R. 1995. Lake trout rehabilitation in Lake Erie: a case of history. *J. Great Lakes Res.* 21 (Suppl. 1):65-82.

DesJardine, R.L., Gorenflo, T.K., Payne, R.N., and Schrouder, J.D. 1995. *Fish community objectives for Lake Michigan.* Great Lakes Fish. Comm. Spec. Publ. 95-1. 38pp.

Elrod, J.H., O'Gorman, R., Schneider, C.P., Eckert, T.H., Schaner, T., Bowlby, J.N., and Schleen, L.P. 1995. Lake trout rehabilitation in Lake Ontario. *J. Great Lakes Res.* 21 (Suppl. 1): 83-107.

Eshenroder, R.L., Holey, M.E., Gorenflo, T.K., and Clark, R.D., Jr. 1995a. *Fish community objectives for Lake Michigan.* Great Lakes Fish. Comm. Spec. Publ. 95-3. 56pp.

Eshenroder, R.L., Payne, N.R., Johnson, J.E., Bowen II, C.A., and Ebener, M.P. 1995b. Lake trout rehabilitation in Lake Huron. *J. Great Lakes Res.* 21 (Suppl. 1):108-127.

Hansen, M.J. 1999. Lake trout in the Great Lakes: basinwide stock collapse and binational restoration. In *Great Lakes Fisheries Policy and Management.* Edited by W.W. Taylor and C.P. Ferreri, Michigan State University Press, East Lansing, MI. pp. 417-454.

Hansen, M.J. (ed.). 1996. *A lake trout restoration plan for Lake Superior.* Great Lakes Fishery Commission, 34pp.

Holey, M.E., Rybicki, R.R., Eck, G.W., Brown,, E.H., Jr., Marsden, J.E., Lavis, D.S., Toneys, M.L., Trudeau, T.N., and Horrall, R.M. 1995. Progress toward lake trout restoration in

Lake Michigan. *J. Great Lakes Res.* 21 (Suppl. 1):128-151.

Horns, W.H., Bronte, C.R., Busiahn, T.R., Ebener, M.P., Eshenroder, R.L., Gorenflo, T., Kmiecik, N., Mattes, W., Peck, J.W., Petzold, M., Schreiner, D.R. 2003. *Fish community objectives for Lake Superior.* Great Lakes Fish. Comm. Spec. Publ. 03-01. 78pp.

Lake Superior Lake Trout Technical Committee (LSLTTC). 1986. A lake trout restoration plan for Lake Superior. In *Minutes of the Lake Superior Committee (1986 annual minutes)*, Ann Arbour, MI, Great Lakes Fishery Commission, March 20, 1986. Lake Trout Task Group. 1985. *A Strategic Plan for the rehabilitation of lake trout in eastern Lake Erie.* Lake Erie Committee. Ann Arbor, MI.

Lantry, B.F., Eckert, T.H., O'Gorman, R., and Owens, R.W. 2003. Lake trout rehabilitation in Lake Ontario, 2002. In: *NYDEC Annual Report to the Great Lakes Fishery Commission's Lake Ontario Committee*, March, 2003.

Ryan, P.A., Knight, R., MacGregor, R., Towns, G., Hoopes, R., and Culligan, W. 2003. *Fish-community goals and objectives for Lake Erie.* Great Lakes Fish. Comm. Spec. Publ. 03-02. 56pp.

Schneider, C.P., Schaner, T., Orsatti, S., Lary, S., and Busch, D. 1997. *A Management Strategy for Lake Ontario Lake Trout*. Report to the Lake Ontario Committee, Great Lakes Fishery Commission.

Wilberg, M. J., Hansen, M.J., and Bronte, C.R. 2003. Historic and modern density of wild lean lake trout in Michigan waters of Lake Superior: implications for restoration goals. *N. Am. J. of Fisheries Management.* 23:100-108.

Authors' Commentary

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.

Benthos Diversity and Abundance - Aquatic Oligochaete Communities

Indicator #104

This indicator report was prepared in 2003.

Assessment: Mixed, Trend Not Assessed

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. 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. Slowly, degraded waters and substrates, especially in shallow areas, began to improve in quality. By the early 1980s, abatement programs and natural biological processes changed habitats to the point where aquatic species tolerant of heavy pollution began to be replaced by species intolerant of heavy pollution.

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 and Figure 2). Most index values from sites in the upper lakes are relatively low and fall into the oligotrophic category, whereas index values from sites in known areas of higher productivity (e.g., nearshore southeastern Lake Michigan; Saginaw Bay, Lake Huron) exhibit higher index values. Sites in Lake Erie, which exhibit the highest index values, generally fall in the mesotrophic to eutrophic range, while in Lake Ontario nearshore sites are classified as mesotrophic, and offshore sites are oligotrophic.

Pressures

At present, future pressures that may change suitability of habitat for aquatic oligochaete communities are unknown.

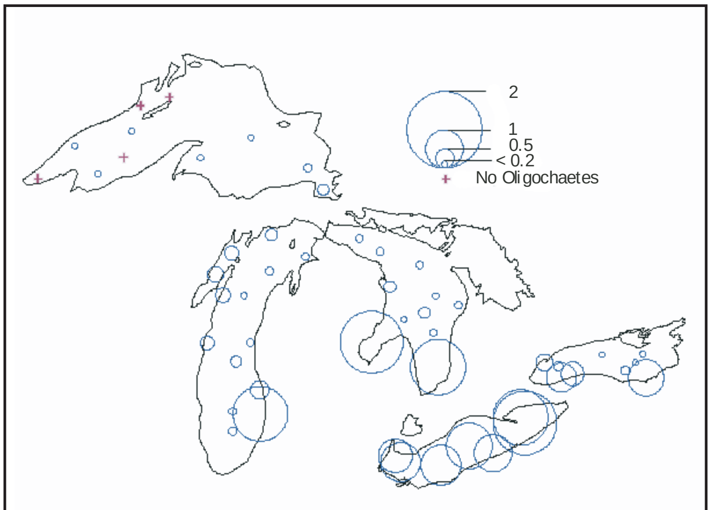

Figure 1. Milbrink's Modified Environmental Index applied to benthic oligochaete communities in the Great Lakes. Data are from 1999, U.S. Environmental Protection Agency-Great Lakes National Program Office Biological Open Water Surveillance Program of the Laurentian Great Lakes 1999, January 2002.
Source: Barbiero and Tuchman 2002

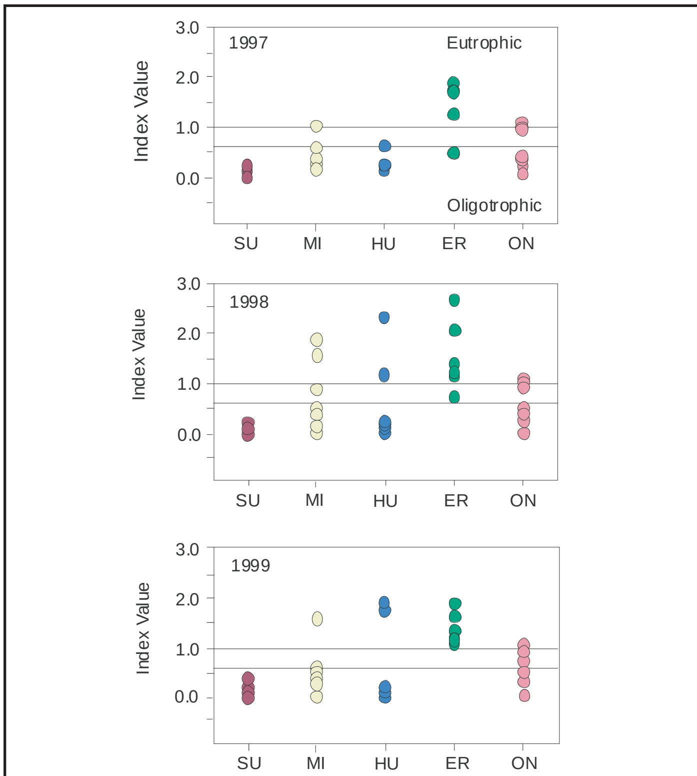

Figure 2. Scatter plots of values of Milbrink's (1983) Modified Environmental Index, applied to data from GLNPO's 1997-1999 summer surveys.
Source: U.S. Environmental Protection Agency, 1997-1999

Undoubtedly, pollution abatement programs and natural processes will 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 an unforeseen source.

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.

Acknowledgments

Authors: Don W. Schloesser, U.S. Geological Survey, Ann Arbor, MI;
Richard P. Barbiero, Dyncorp I & ET, Inc., Chicago, IL; and
Mary Beth Giancarlo, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL.

Sources

Barbiero, R.P., and Tuchman, M.L. 2002. *Results From Biological Open Water Surveillance Program of the Laurentian Great Lakes 1999*. U.S. Environmental Protection Agency, Great Lakes National Program, Chicago, IL. EPA-905-R-02-001.

Data Source: U.S. Environmental Protection Agency, Great Lakes National Program Office, Biological Open Water Surveillance Program of the Laurentian Great Lakes, 1997-1999.

Milbrink, G. 1983. An improved environmental index based on the relative abundance of oligochaete species. *Hydrobiologia* 102:89- 97.

Quality Assurance Project Plan for the Great Lakes Water Quality Surveys, version March 2002, Great Lakes National Program Office. In the Sampling and Analytical Procedures for GLNPO's Open Lake Water Quality Survey of the Great Lakes manual, version 2002, GLNPO-contact: Louis Blume, 312-353-2317, blume.louis@epa.gov.

Authors' Commentary

Biological responses of aquatic oligochaete communities are excellent indicators of substrate quality, and when combined with a temporal component allow the determination of subtle changes in environmental quality, possibly decades before single species indicators. It is only in the past few years, however, that this benthic index has been routinely applied to the open waters of all the Great Lakes. It is therefore critical that routine monitoring of oligochaete communities in the Great Lakes continue. In addition, oligochaete taxonomy is a highly specialized and time consuming discipline, and the classification of individual species 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. It should be noted that even though this index only addresses responses to organic enrichment in sediments, it may be used with other indicators to assess the effects of other sediment pollutants.

Phytoplankton Populations

Indicator #109

This indicator report was prepared in 2003.

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

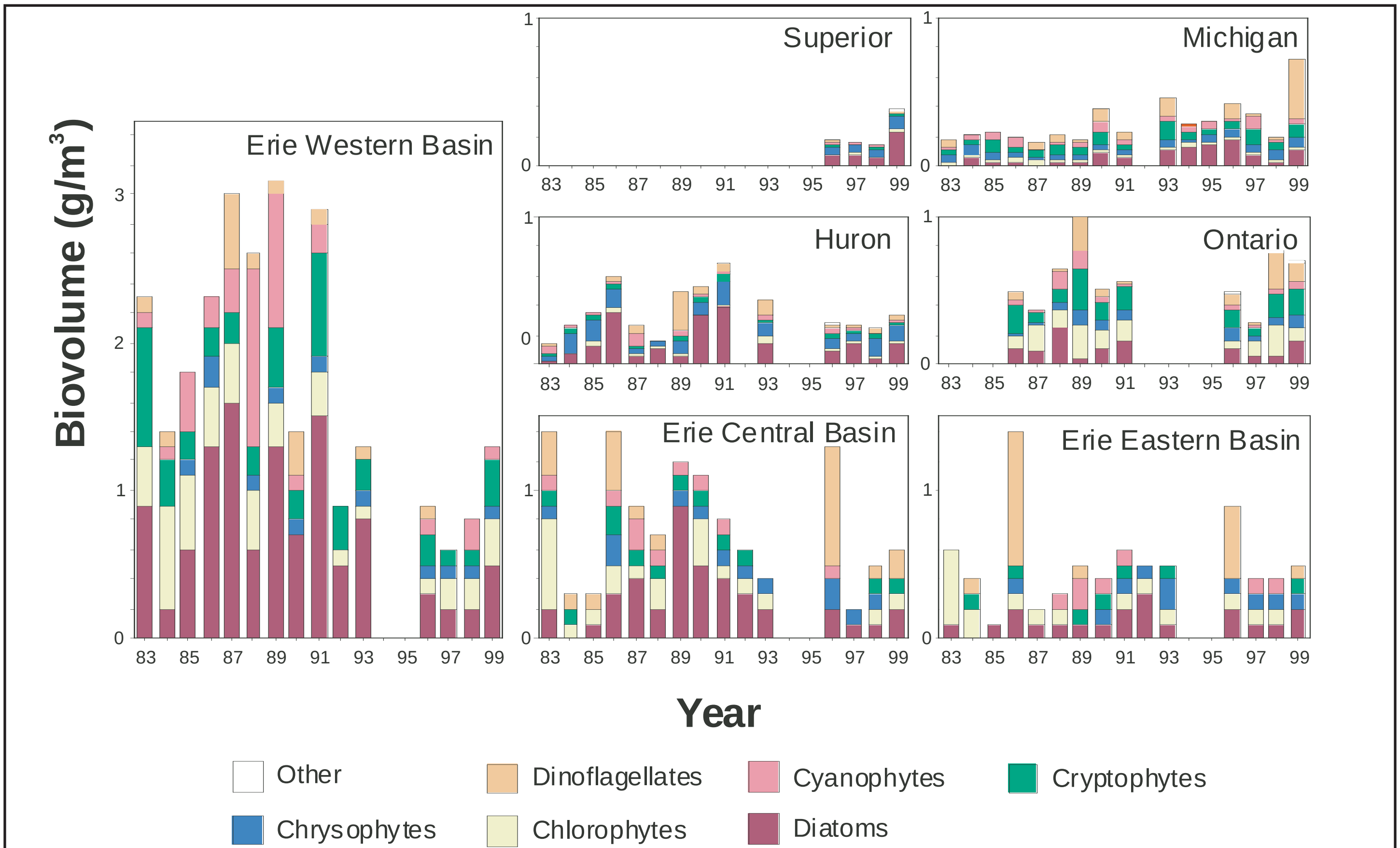

Figure 1. Trends in phytoplankton biovolume (g/m³) and community composition in the Great Lakes 1983-1999. Samples were collected from offshore, surface waters during August.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office

significant increase in the size of summer diatom populations occurred during the 1990s. This was most likely due to the 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
Authors: Richard P. Barbiero, DynCorp, A CSC company, Chicago, IL, rick.barbiero@dyncorp.com; and
Marc L. Tuchman, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL, tuchman.marc@epa.gov.

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".

Phosphorus Concentrations and Loadings

Indicator #111

Assessment: Mixed, Undetermined

Purpose

- To assess total phosphorus levels in the Great Lakes; and
- To support the evaluation of trophic status and food web dynamics in the Great 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 (Great Lakes Water Quality Agreement (GLWQA) Annex 3, United States and Canada 1987). "Delisting" guidelines for eutrophication or undesirable algae specify "no persistent water quality problems (e.g., dissolved oxygen, depletion of bottom waters, nuisance algal blooms or accumulations, and decreased water clarity) attributed to cultural eutrophication." 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 Table 1.

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.
Source: Phosphorus Management Strategies Task Force, 1980

State of the Ecosystem

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 manmade sources.

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 and harbours. Annual loadings of phosphorus have decreased in part due to changes in agricultural practices (e.g., conservation tillage and integrated crop management), promotion of reduced-phosphorus laundry detergents, and improvements made to sewage treatment plants and sewer systems (Neilson *et al*. 1995).

Average phosphorus 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 levels. In Lakes Ontario and Huron, although most offshore waters meet the desired guideline, some offshore and nearshore areas and embayments experience elevated levels which could promote nuisance algae growths such as the attached green alga, *Cladophora*.

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, possibly contributing to increasing phosphorus loads.

Management Implications

Because of its key role in productivity and food web dynamics of the Great Lakes, phosphorus concentrations continue to be monitored by environmental and fishery agencies. Future activities that are likely to be needed include: 1) Assessment of the capacity and operation of existing sewage treatment plants in the context of increasing human populations being served. Upgrades in construction or operations may be required; 2) Sufficient tributary monitoring to support the calculation of annual loadings of phosphorus to each Great Lake by source category (i.e., sewage treatment plans, tributaries, etc.). If the phosphorus concentrations remain stable at or below the maximum target levels for most of the lakes, loadings information might be useful, but not critical.

Acknowledgments

Authors: Scott Painter, Environment Canada, Burlington, ON; and
Glenn Warren, U.S. Environmental Protection Agency, Chicago, IL.

Sources

Neilson, M., L'Italien, S., Glumac, V., Williams, D., and Bertram, P. 1995. *Nutrients: Trends and System Response*. State of the Lakes Ecosystem Conference Background Paper. Environment Canada and U.S. Environmental Protection Agency. EPA 905-R95-015. 34pp.

Phosphorus Management Strategies Task Force. 1980. *Phosphorus Management for the Great Lakes*. Final Report to the International Joint Commission, Great Lakes Water Quality Board and Great

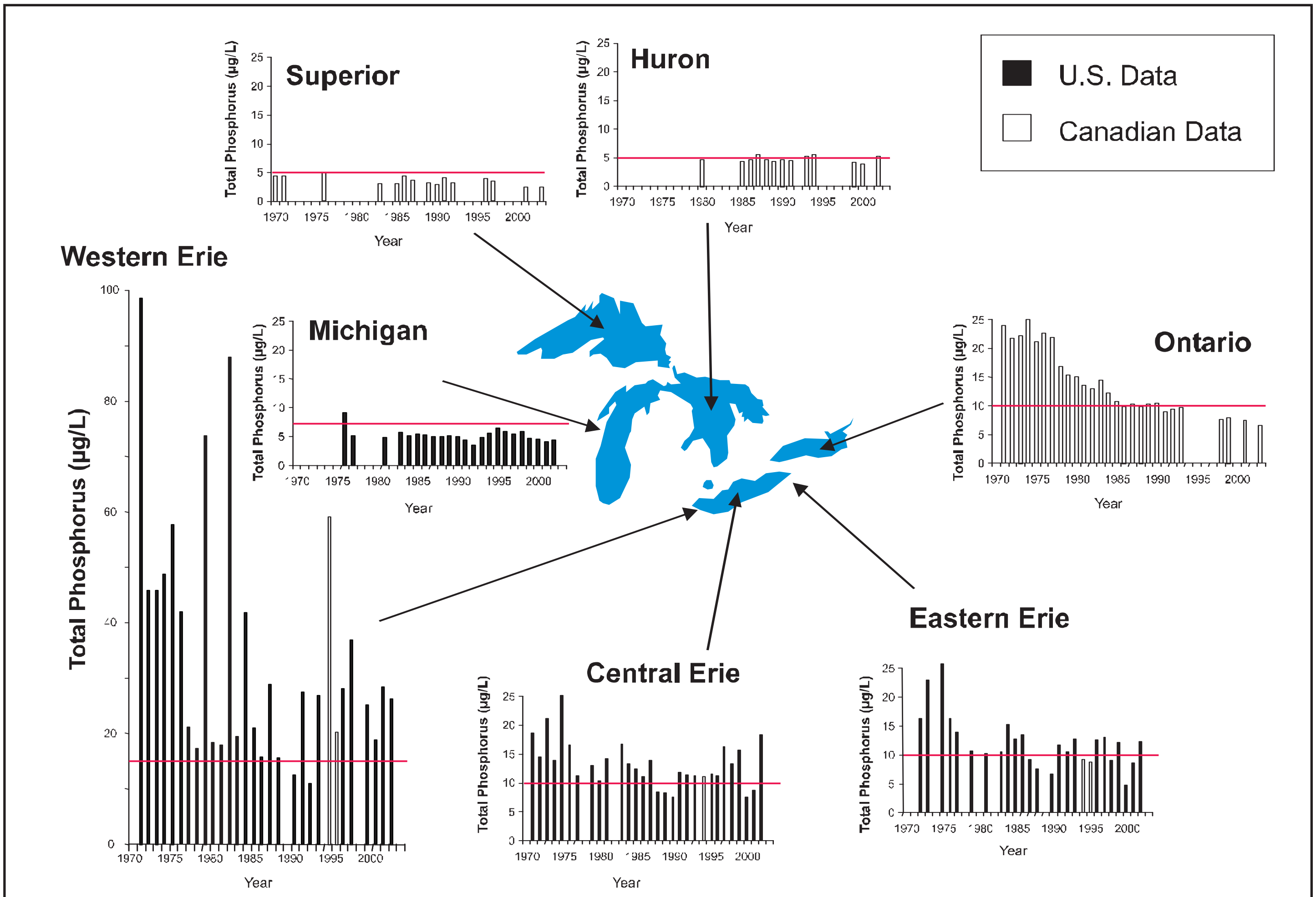

Figure 1. Total phosphorus trends in the Great Lakes 1971-2003 (Spring, Open Lake, Surface). Blank indicates no sampling. Horizontal line on each graphic represents the expected phosphorus concentration in each lake if the annual phosphorus loading targets, as listed in the Great Lakes Water Quality Agreement, are maintained. White bar graphs represent Environment Canada data. Black bar graphs represent U.S. Environmental Protection Agency data.
Source: Environmental Conservation Branch, Environment Canada and U.S. Environmental Protection Agency

Lakes Science Advisory Board, Windsor, ON. 125pp.
United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington.

Violeta Richardson, Environmental Conservation Branch, Environment Canada.

Authors' Commentary
The analysis of phosphorus concentrations in the Great Lakes is ongoing and reliable. However, a coordinated enhanced monitoring program is required with agreement on specifics such as analytical and field methodologies, sampling locations, inclusion of nearshore and embayment sites, determination of the indicator metric and the index. 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 for all lakes except Lake Erie, for which loadings information is available up to 2002, and Lake Michigan, for which information is available for 1994 and 1995. Efforts to collect data to support loadings calculations should be reinstated for at least Lake Erie. Otherwise, the loadings component of this indicator will remain unreported, and changes in the contribution of phosphorus from different sources may go undetected.

Contaminants in Young-of-the-Year Spottail Shiners

Indicator #114

Assessment: Mixed, Improving

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 (CCME) guidelines for total dichlorodiphenyl-trichloroethane (DDT) and dioxins and furans were not used in previous State of the Lakes Ecosystem Conference (SOLEC) reports and are much more stringent than the NYSDEC Fish Flesh Criteria that they replace. Contaminants monitored in forage fish and their respective guidelines are listed in Table 1.

State of the Ecosystem

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 1998); [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.
The guideline for Mirex is below the detection limit. Therefore, if Mirex is detected, the guideline has been exceeded.

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

Contaminant levels in fish are important indicators of contaminant levels in an ecosystem because organochlorine chemicals bioaccumulate in fish tissues. 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.

With the incorporation of the new CCME guidelines, the total DDT tissue residue criterion is exceeded at most locations. After total DDT, polychlorinated biphenyls (PCBs) are the contaminants most frequently exceeding the guideline. Mirex is detected and exceeds the guideline only at Lake Ontario locations. 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 in recent years they have declined to less than the detection limit (20 n/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, and they continued to exceed the guideline in the most recent collection (2001).

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 near 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

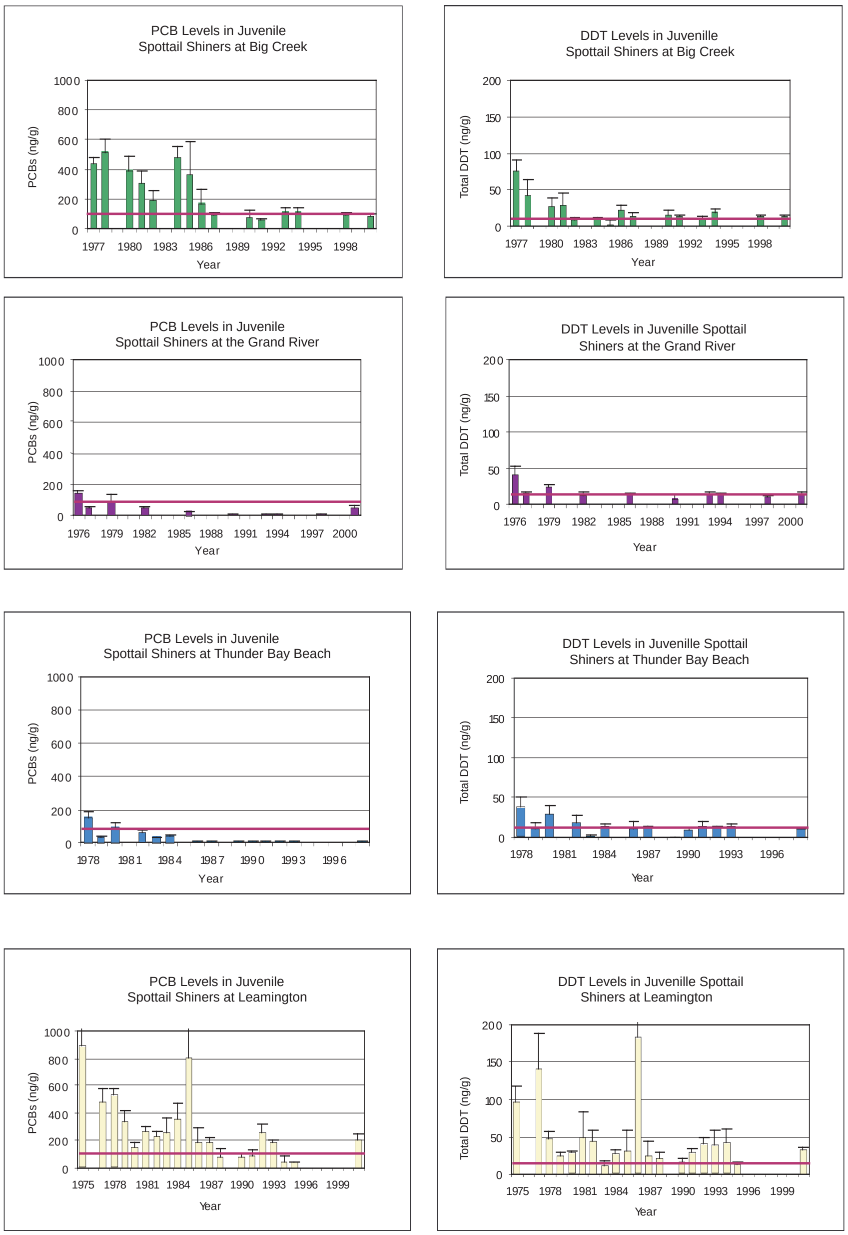

Figure 1. PCB and total DDT levels in juvenile spottail shiners from four locations in Lake Erie. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.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

Nottawasaga River the highest concentration of PCBs was observed in 1977 (90 ng/g). Concentrations declined to less than the detection limit by 1987. In 2002, PCBs 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). Due to the scarcity of spottail shiners, 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 were also found 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 was the highest concentration observed in juvenile fish from any Lake Superior site to date. At Jackfish Bay and the Kam River, total DDT levels have been below the guideline each year, except for the Kam River in 1991 when levels rose above the guideline 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.

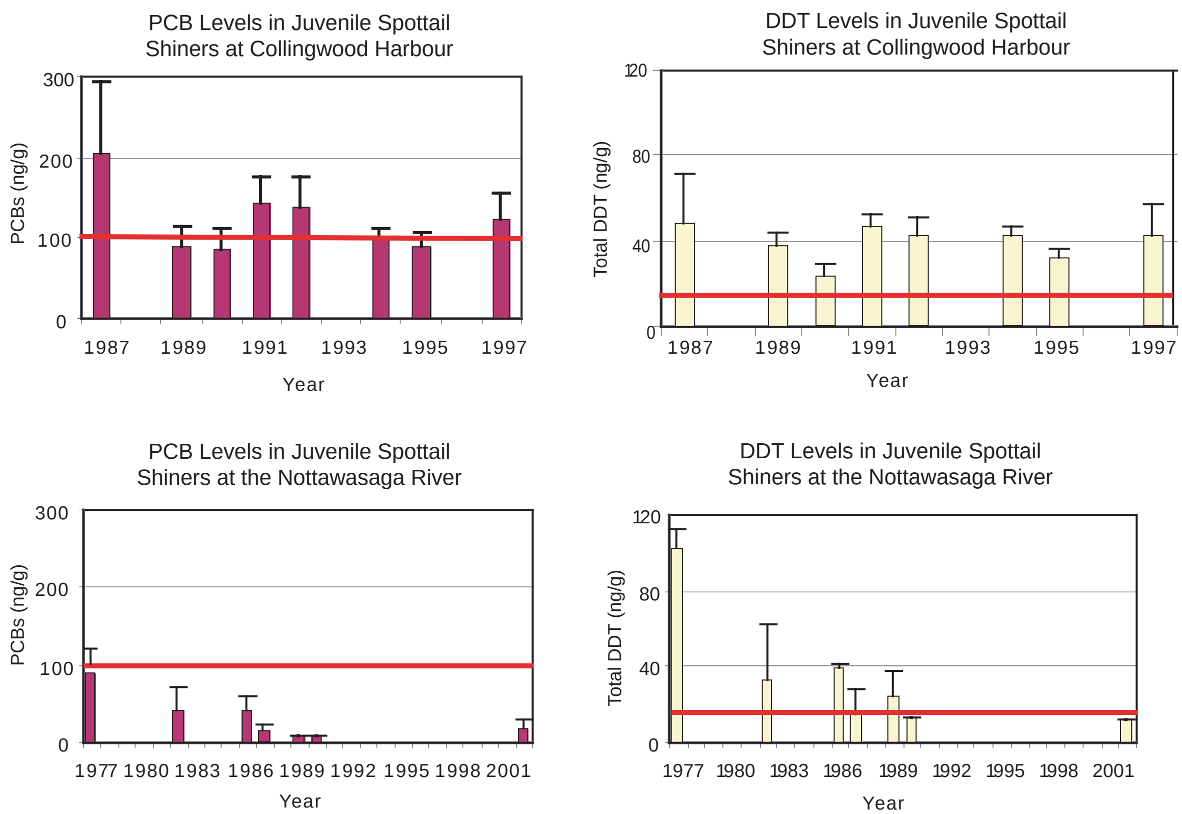

Figure 2. PCB and total DDT levels in juvenile spottail shiners from two locations in Lake Huron. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.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

Mirex has been detected intermittently at all five locations. The maximum concentration was 37 ng/g at the Credit River. Since 1992, mirex has been below the detection limit at all of these locations.

Lake Michigan
No spottail shiners were sampled from Lake Michigan.

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.

Sources

Canadian Council of Ministers of the Environment (CCME). 2001. Canadian Environmental Quality Guidelines.

Newell, A.J., Johnson, D.W., and Allen, L.K. 1987. *Niagara River biota contamination project: fish flesh criteria for piscivorous wildlife.* Technical Report 87-3. New York State Department of Environmental Conservation, Albany, NY.

Scheider, W.A., Cox, C., Hayton, A., Hitchin, G., and Vaillancourt, A. 1998. Current status and temporal trends in concentrations of persistent toxic substances in sport fish and juvenile forage fish in the Canadian waters of the Great Lakes. *Environ. Monit. Assess.* 53:57-76.

Suns, K., and Rees, G. 1978. Organochlorine contaminant residues in young-of-the-year spottail shiners from Lakes Ontario, Erie, and St. Clair. *J. Great Lakes Res.* 4:230-233.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987.* Ottawa and Washington.

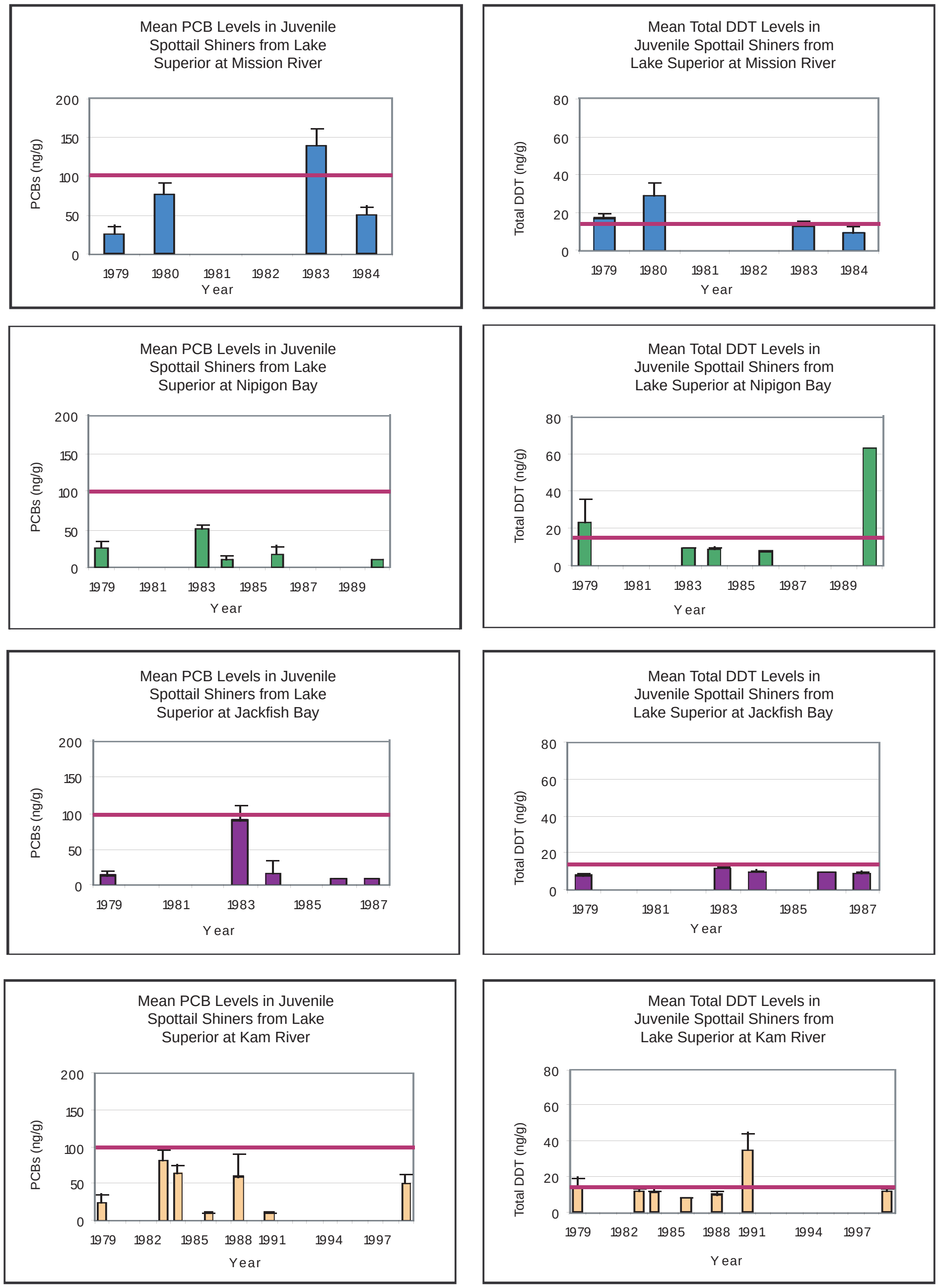

Figure 3. PCB and total DDT levels in juvenile spottail shiners from four locations in Lake Superior. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean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

Authors' Commentary

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 most of the consumption advisories and restrictions on sport fish from this lake (Scheider *et al*., 1998), 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 more difficult to find than it once was. 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 will improve temporal and spatial trend data and result in a more complete dataset for the Great Lakes.

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

Contaminants in Colonial Nesting Waterbirds

Indicator #115

Assessment: Mixed, Improving

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 continuous 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 (Braune *et al.* 2003).

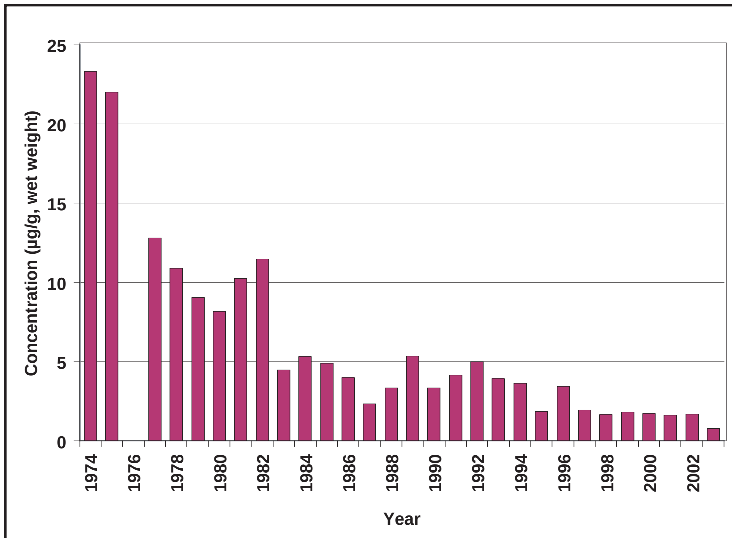

Figure 1. Temporal trends in concentration of DDE in Herring Gull eggs, Toronto Harbour, 1974-2003.
Source: Environment Canada, Herring Gull Monitoring Program

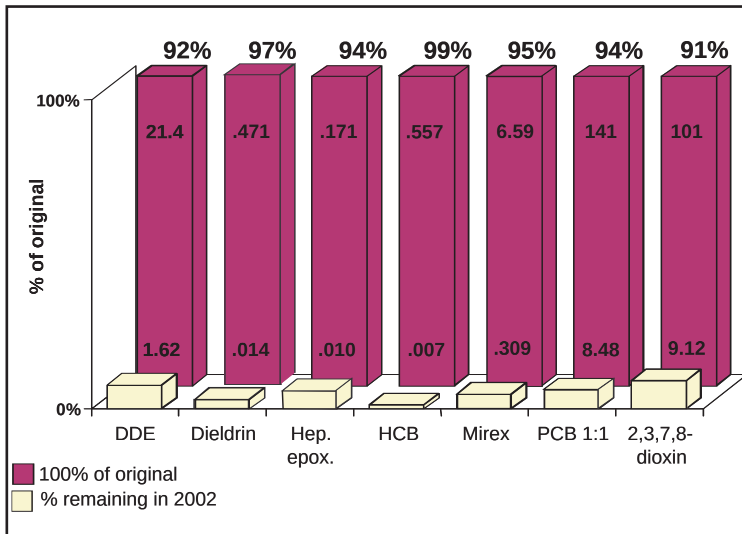

Figure 2. Mean contaminant concentrations and percent decline of 7 contaminants in Herring Gull eggs from year of first analysis (1974 for all compounds except 2,3,7,8-dioxin which was first analyzed in 1984) to present (2002), Snake Island, Lake Ontario. Concentrations in µg/g wet weight except for dioxin in pg/g wet weight.
Source: Environment Canada, Herring Gull Monitoring Program

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 a minimum of 50% and many have declined more than 90% since the program began in 1974 (Figure 2). In 2003, 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

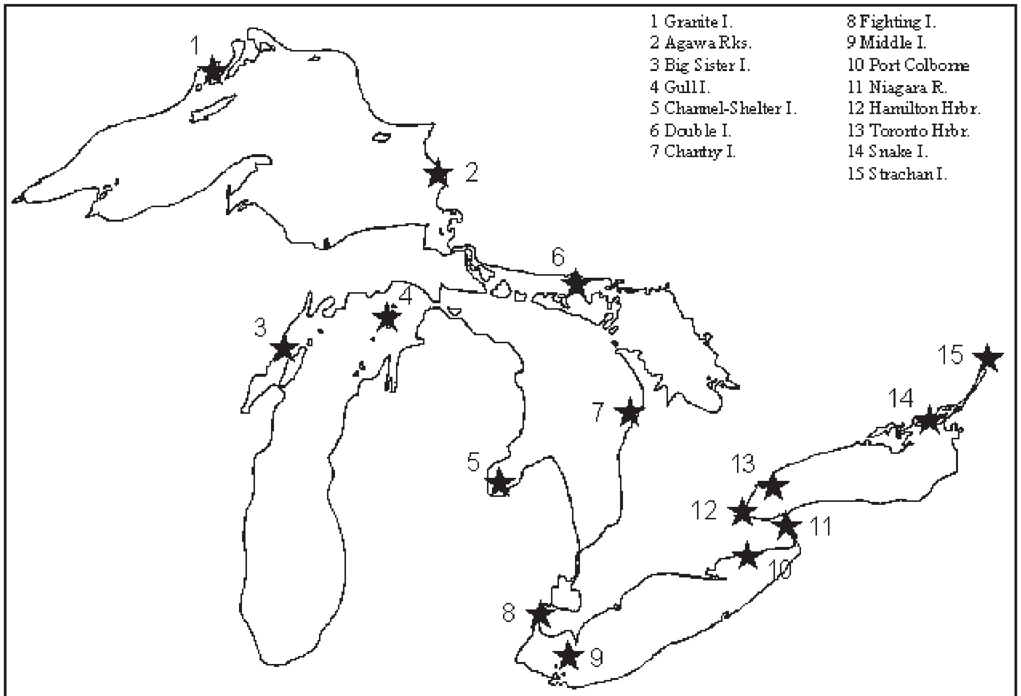

Figure 3. The distribution and locations of the 15 Herring Gull Annual Monitoring Colonies. Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service

Colonies (Figure 3) were analysed for temporal trends (N=105 comparisons). Analysis showed that in 72% of cases (76/105), the contaminants were decreasing as fast as or faster in recent years than they had in the past. In 22% of cases (23/105), contaminants were decreasing slower 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). Mirex, PCBs and DDE were three compounds showing the most frequent reduction in their rates of decline.

The sole exception to these declining herring gull egg contaminant concentrations appears to be brominated diphenyl ethers. These compounds, which are used as fire retardants in plastics, furniture cushions, etc., have increased dramatically in gull eggs in the last 20 years (Norstrom *et al.* 2002).

A comparison of concentrations of seven contaminants (TCDD, PCBs, HCB, DDE, HE, dieldrin and mirex) at the 15 sites in 2001 and 2003 (N=105 comparisons) was made to show the variability in a short-term (two year) assessment. With one exception, the 105 comparisons were evenly divided; 49.5% of the cases (52/105) had decreased since 2001 and the other 49.5% of the cases (52/105) had increased. DDE, dieldrin and PCBs were the most frequently declining contaminants, while mirex and TCDD were the most frequently increasing contaminants. One percent of the cases (1/105), involving HCB, showed no change in levels from 2001 to 2003 (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).

Another extremely useful way in which the Herring Gull data are used is in the determination of spatial patterns. For example, contaminant "hot spots" for wildlife have been identified by testing for spatial patterns among the 15 Annual Monitor Colonies (Weseloh *et al.* 1990, Ewins *et al.* 1992, Weseloh *et al.* In review). Mean contaminant values for 1998-2002 showed that the eggs from Channel-Shelter I. (Saginaw Bay, Lake Huron) had the greatest concentrations of PCBs, TCDD and HCB; those from Gull I. (northern Lake Michigan) had the greatest concentrations of DDE, dieldrin and HE; and those from Snake I. (eastern Lake Ontario) had the greatest concentrations of mirex (Figure 5). There was no significant variation among sites for mercury. Overall, when ranking the sites, and weighting compounds according to fish flesh criteria for the protection of pis-

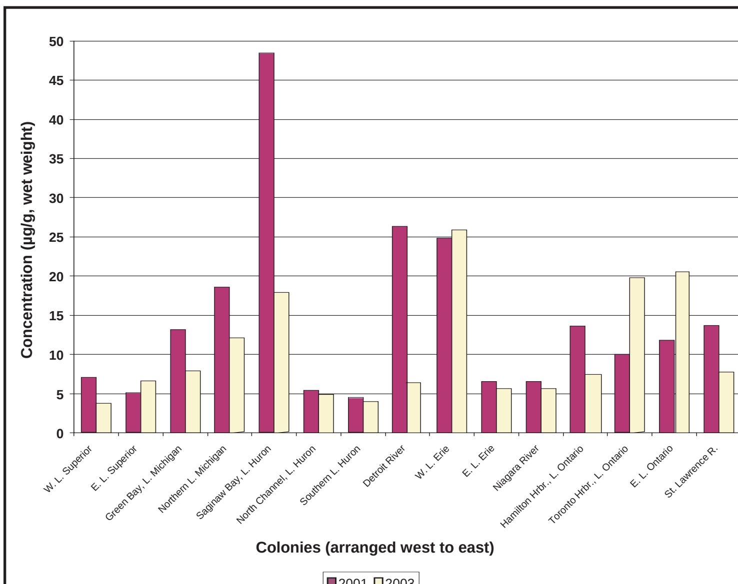

Figure 4. A comparison of PCB concentrations at all sites for 2001 and 2003. Note the between year differences as well as the variation among sites.
Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service

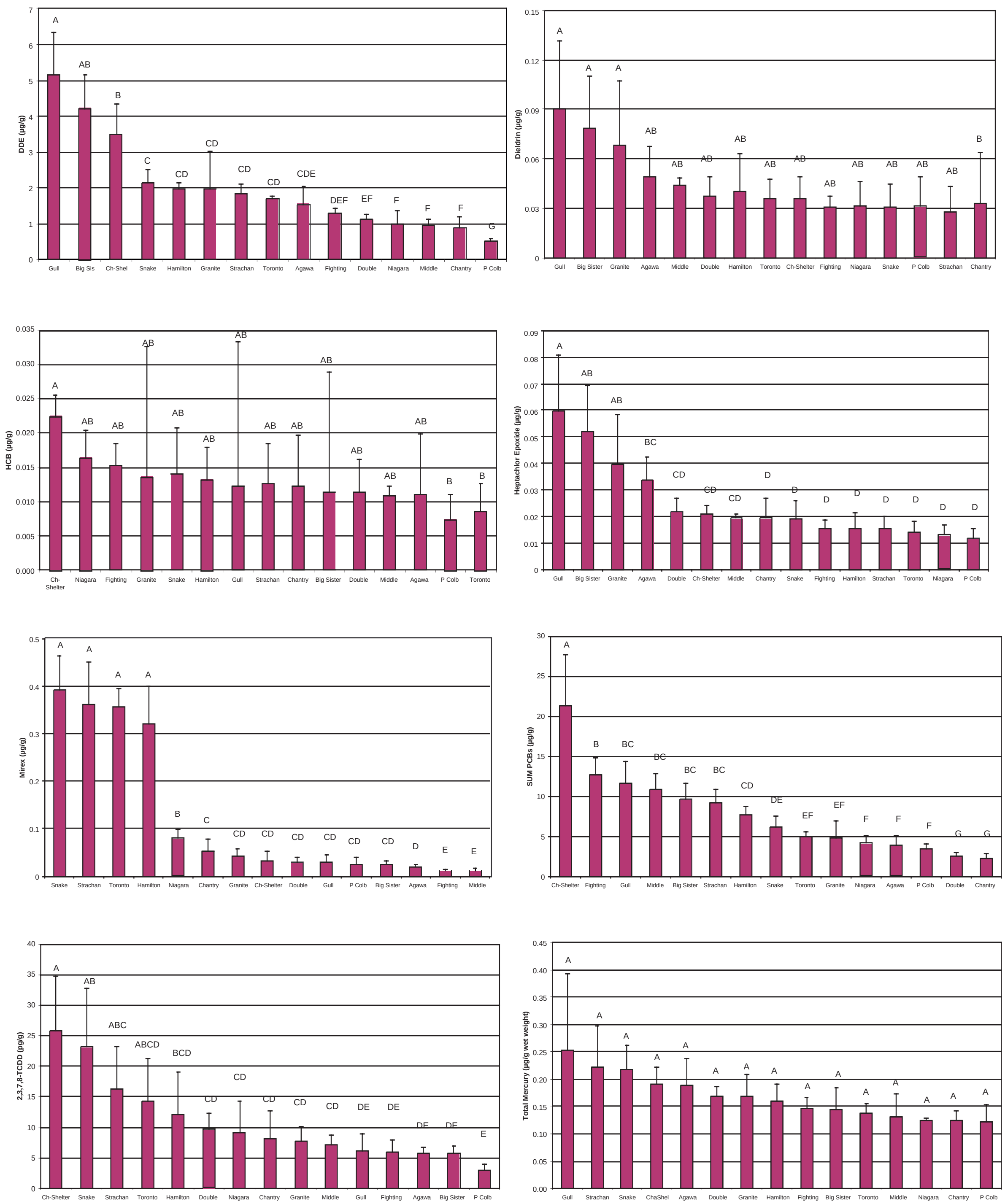

Figure 5. Spatial trends, 1998-2002. Means with the same letter are not significantly different (SNK Test). Error bars represent one standard deviation from the mean. Concentrations are reported in µg/g wet weight, except 2,3,7,8-dioxin which is reported as pg/g wet weight.
Source: Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service

civorous wildlife (Newell *et al.* 1987), Channel-Shelter I., Strachan I. (St. Lawrence River) and Gull I. were the three most contaminated sites. Agawa Rocks, Chantry I. and Port Colborne ranked as the three least contaminated sites (Weseloh *et al.* In review).

In terms of gross ecological effects of contaminants on colonial waterbirds, e.g. eggshell thinning, failed reproductive success and population declines, most species seem to have recovered. Populations of most species have increased over the past 25-30 years, e.g. see Figure 6 (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

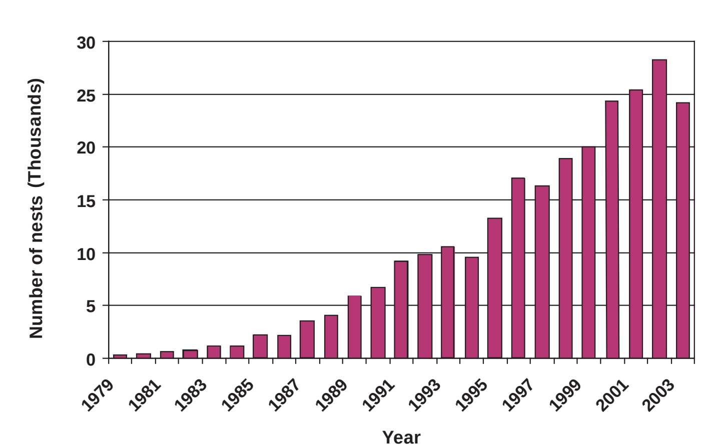

Figure 6. Double-crested Cormorant nests (breeding pairs) on Lake Ontario, 1979-2003.
Source: Environment Canada, Canadian Wildlife Service

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.

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.

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.

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Sources

Austen, M.J., Blokpoel, H., and Tessier, G.D. 1996. *Atlas of colonial waterbirds nesting on the Canadian Great Lakes, 1989-1991*. Part 4. Marsh-nesting terns on Lake Huron and the lower Great Lakes system in 1991. Canadian Wildlife Service (CWS), Ontario Region, Technical Report No. 217. 75pp.

Bishop, C.A., Weseloh, D.V., Burgess, N.B., Norstrom, R.J., Turle, R., and Logan, K.A. 1992. *An atlas of contaminants in eggs of colonial fish-eating birds of the Great Lakes (1970-1988).* Accounts by location and chemical. Volumes 1 & 2. Canadian Wildlife Service (CWS), Ontario Region, Technical Report Nos. 152 and 153. 400 pp. and 300 pp.

Blokpoel, H., and Tessier, G.D. 1993-1998. *Atlas of colonial waterbirds nesting on the Canadian Great Lakes, 1989-1991*. Parts 1-3, 5. Canadian Wildlife Service (CWS), Ontario Region, Technical Report Nos. 181, 225, 259, 272. 93 pp, 153 pp, 74 pp, 36 pp.

Braune B.M., Hebert, C.E., Benedetti, L.S., and Malone, B.J. 2003. *An Assessment of Canadian Wildlife Service Contaminant Monitoring Programs.* Canadian Wildlife Service (CWS), Technical Report No. 400. Headquarters. Ottawa, ON. 76 pp.

Custer, T.W., Custer, C.M., Hines, R.K., Gutreuter, S., Stromborg, K.L., Allen, P.D., and Melancon, M.J. 1999. Organochlorine contaminants and reproductive success of Double-crested Cormorants from Green Bay, Wisconsin, USA. *Environ. Toxicol. & Chem.* 18:1209-1217.

Cuthbert, F.J., McKearnan, J., and Joshi, A.R. 2001. *Distribution and abundance of colonial waterbirds in the U.S. Great Lakes, 1997 - 1999.* Report to U.S. Fish and Wildlife Service, Twin Cities, Minnesota.

Environment Canada. 2003. *Fish and wildlife health effects in the Canadian Great Lakes Areas of Concern.* Great Lakes Fact Sheet. Canadian Wildlife Service (CWS), Ontario Region, Downsview, ON. Catalogue No. CW/66-223/2003E. ISBN 0-662-34076-0.

Ewins, P.J., Weseloh, D.V., and Mineau, P. 1992. Geographical distribution of contaminants and productivity measures of Herring Gulls in the Great Lakes: Lake Huron 1980. *J. Great Lakes Res.* 18(2):316-330.

Fox, G.A. 1993. What have biomarkers told us about the effects of contaminants on the health of fish-eating birds in the Great Lakes? The theory and a literature review. *J. Great Lakes Res.* 19:722-736.

Fox, G.A., Kennedy, S.W., Norstrom, R.J., and Wgfield, D.C. 1988. Porphyria in herring gulls: a biochemical response to chemical contamination in Great Lakes food chains. *Environ. Toxicol. & Chem.* 7:831-839.

Grasman, K.A., Fox, G.A., Scanlon, P.F., and Ludwig, J.P. 1996. Organochlorine associated immunosuppression in prefledging Caspian terns and herring gulls from the Great Lakes: an ecoepidemiological study. *Environmental Health Perspectives* 104:829-842.

Havelka, T., and Weseloh, D.V. In review. Continued growth and expansion of the Double-crested Cormorant (*Phalacrocorax auritus*) population on Lake Ontario, 1982-2002.

Hebert, C.E., Weseloh, D.V., Havelka, T., Pekarik, C., and Cuthbert, F. In review. Lake Erie colonial waterbirds: Trends in populations, contaminant levels and diet. The State of Lake Erie. In *Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society*, ed. M. Munawar.

Jermyn-Gee, K., Pekarik, C., Havelka, T., Barrett, G., and Weseloh, D.V. 2005. *An atlas of contaminants in eggs of colonial fish-eating birds of the Great Lakes (1998-2001).* Accounts by location (Vol. I) & chemical (Vol. II). Technical Report No. 417. Canadian Wildlife Service (CWS), Ontario Region, Downsview, ON. Catalogue No. CW69-5/417E-MRC. ISBN – 0-662-37427-4.

Morris, R.D., Weseloh, D.V., and Shutt, J.L. 2003. Distribution and abundance of nesting pairs of Herring Gulls (*Larus argentatus*) on the North American Great Lakes. *J. Great Lakes Res.* 29:400-426.

Newell, A.J., Johnson, D.W., and Allen, L.K. 1987. *Niagara River Project: Fish flesh criteria for piscivorous wildlife*. New York State Department of Environmental Conservation, Technical Report 87-3.

Norstrom, R.J., Simon, M., Moisey, J., Wakeford, B., and Weseloh, D.V.C. 2002. Geographical distribution (2000) and temporal trends (1981-2000) of brominated diphenyl ethers in Great Lakes Gull eggs. *Environ. Sci. & Technol.* 36:4783-4789.

Pekarik, C., and Weseloh, D.V. 1998. Organochlorine contaminants in Herring Gull eggs from the Great Lakes, 1974-1995: change point regression analysis and short term regression. *Environ. Monit. & Assess.* 53:77-115.

Pekarik, C., Weseloh, D.V., Barrett, G.C., Simon, M., Bishop, C.A., and Pettit, K.E. 1998. An atlas of contaminants in the eggs of fish-eating colonial birds of the Great Lakes (1993-1997). Accounts by location & chemical. Volumes I & 2. Canadian Wildlife Service (CWS), Ontario Region, Technical Report Nos. 321 and 322. 245 pp. and 214 pp.

Pettit, K.E., Bishop, C.A., Weseloh, D.V., and Norstrom, R.J. 1994. *An atlas of contaminants in eggs of colonial fish-eating birds of the Great Lakes (1989-1992).* Accounts by location & chemical. Volumes 1 & 2. Canadian Wildlife Service (CWS), Ontario Region, Technical Report Nos. 194 and 195. 319 pp. and 300 pp.

Scharf, W.C., and Shugart, G.W. 1998. Distribution and abundance of gull, tern and cormorant nesting colonies of the U.S. Great Lakes, 1989 and 1990. In *A.S. Publication No. 1* eds. W.W. Bowerman and Roe, Sault Ste. Marie, MI: Gale Gleason Environmental Institute, Lake Superior State University Press.

Weseloh, D.V.C., Pekarik, C., and de Solla, S. In review. Spatial Patterns and Rankings of Contaminant Concentrations in Herring Gull eggs from 15 Sites in the Great Lakes and Connecting Channels, 1998-2002. *Environ. Monit. & Assess*.

Weseloh, D.V.C., Pekarik, C., Havelka, T., Barrett, G., and Reid, J. 2002. Population trends and colony locations of double-crested cormorants in the Canadian Great Lakes and immediately adjacent areas, 1990-2000: a manager's guide. *J. Great Lakes Res.* 28:125-144.

Weseloh D.V., Mineau, P., and Struger, J. 1990. Geographical distribution of contaminants and productivity measures of Herring Gulls in the Great Lakes: Lake Erie and connecting channels 1978/79. *Science of the Total Environment* 91(1990):141-159.

Yauk, C.L., Fox, G.A., McCarry, B.E., and Quinn, J.S. 2000. Induced minisatellite germline mutations in Herring Gulls (*Larus argentatus*) living near steel mills. *Mutation Research* 452:211-218.

Authors' Commentary

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 and factors regulating chemically induced genetic mutations.

Zooplankton Populations

Indicator #116

This indicator report was prepared in 2001. Assessment was reevaluated in 2003. Specific objectives or criteria for assessment have not been determined.

Assessment: Mixed, Trend Not Assessed

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 to cladoceran and cyclopoid crustaceans, 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. A mean individual size of 0.8 mm has been suggested as "optimal" for zooplankton communities sampled with a 153 µm mesh net, although the meaning of deviations from this objective, and the universality of this objective remain unclear. In particular, questions regarding its applicability to dreissenid impacted systems have been raised. In general, calanoid/cladoceran+cyclopoid ratios tend to increase with decreasing nutrient enrichment. Therefore high ratios are desirable. As with individual mean size, though, clear objectives have not presently been defined.

State of the Ecosystem

The most recent available data (1998) suggest that mean individual lengths of offshore zooplankton populations in the three upper lakes and the central basin of Lake Erie exceed the objective of 0.8 mm (Figure 1), suggesting a fish community characterized by a high piscivore/planktivore ratio. Mean individual lengths of zooplankton populations in the western and eastern basins of Lake Erie, as well as most sites in Lake Ontario, were substantially below this objective. Interquartile ranges for most lakes (considering the three basins of Lake Erie separately) were generally on the order of 0.1-0.2 mm, although the size range of zooplankton from Lake Ontario was substantially greater. Historical data from the eastern basin of Lake Erie, from 1985 to 1998, indicate a fair amount of interannual variability, with values from offshore sites ranging from about 0.5 mm to 0.85 mm (Figure 2). As noted above, interpretation of these data are currently problematic. The ratio of calanoids to cladocerans and cyclopoids showed a clear relationship with trophic state. The average value for the oligotrophic Lake Superior was at least four times higher than that for any other lake, while the ratio value for Lakes Michigan and Huron and the eastern basin of Lake Erie were also relatively high (Figure 3). The zooplankton ratios from the western basin of Lake Erie and Lake Ontario were identically low, while the central basin of Lake Erie had an intermediate value. 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, and in fact up to the present. A similar increase was seen in the eastern basin, although some of the data used to calculate the ratio were generated from shallow

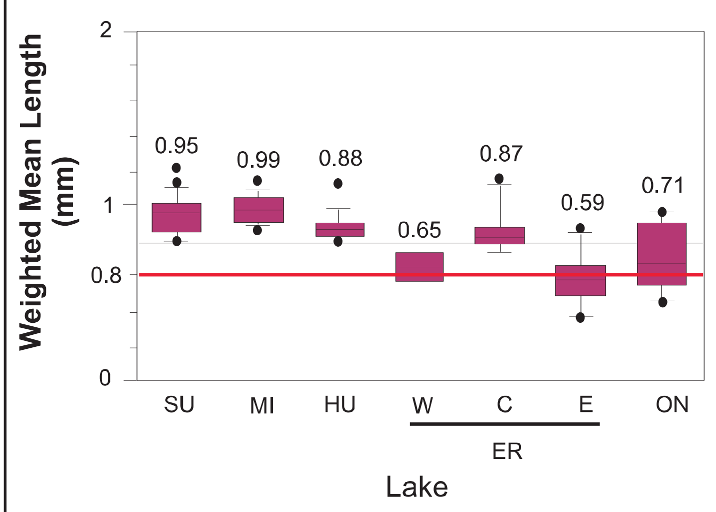

Figure 1. Average individual mean length of zooplankton for the five Great Lakes. Lake Erie is divided into western, central and eastern basins. Length estimates were generated from data collected with 153µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Numbers indicate arithmetic averages.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office, August, 1998

tows and are therefore subject to doubt.

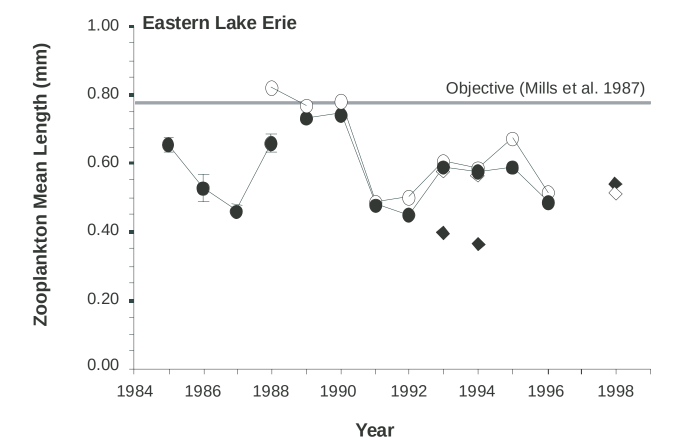

Figure 2. Trend in Jun27-Sep30 mean zooplankton length: NYDEC data (circles) collected with 153µm mesh net, DFP data (diamonds) converted from 64µm to 153µm mesh equivalent. Open symbols = offshore, solid symbols = nearshore (<12m). 1985-1988 are means +/- 1 S.E.
Source: Johannsson *et al*. 1999

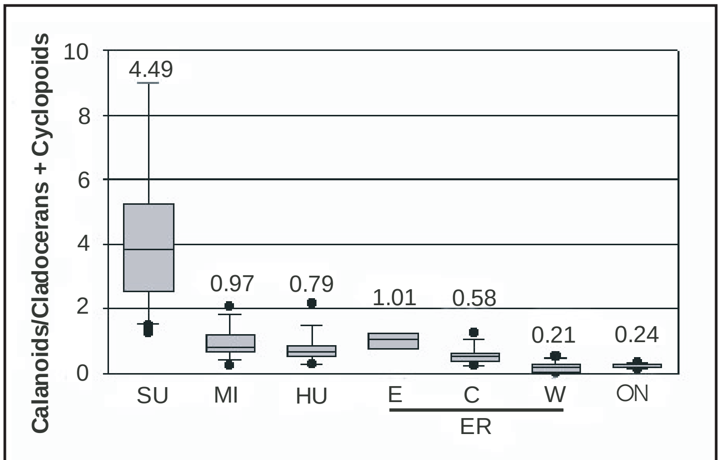

Figure 3. Ratio of biomass of calanoid copepods to that of cladocerans and cyclopoid copepods for the five Great Lakes. Lake Erie (ER) is divided into western, central and eastern basins. Data collected with 153 µm mesh net tows to a depth of 100 metres of the bottom of the water column, whichever was shallower. Numbers indicate arithmetic averages.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office

Pressures

The zooplankton community might be expected to respond to changes in nutrient 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. An exotic predatory cladoceran, *Bythotrephes longimanus*, has already been in the lakes for approximately twenty years, and is suspected to have had a major impact on zooplankton community structure. A second predatory cladoceran, *Cercopagis pengoi*, was first noted in Lake Ontario in 1998, and is expected to spread to the other lakes. In addition, 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.

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.

Acknowledgments

Authors: Richard P. Barbiero, DynCorp, A CSC company, Chicago, IL, rick.barbiero@dyncorp.com;
Marc L. Tuchman, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago IL, tuchman.marc@epa.gov; and
Ora Johannsson, Fisheries and Oceans Canada, Burlington, Ontario Canada.

Sources

Johannsson, O.E., Dumitru, C., and Graham, D.M. 1999. Examination of zooplankton mean length for use in an index of fish community structure and application in Lake Erie. *J. Great Lakes Res*. 25:179-186.

U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL, unpublished data.

Authors' Commentary

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.

Atmospheric Deposition of Toxic Chemicals

Indicator #117

Assessment: Mixed, Improving for polychlorinated biphenyls (PCBs), banned organochlorine pesticides, and dioxins and furans

Mixed, Unchanging for polycyclic aromatic hydrocarbons (PAHs) and mercury

Although concentrations and loadings of banned or restricted toxic chemicals (PCBs and banned organochlorine pesticides such as dichlorodiphenyl-trichloroethane [DDT]) and concentrations of dioxins and furans are generally decreasing, concentrations and inputs of other substances are either unchanging (PAHs, mercury) or possibly increasing (polybrominated diphenyl ethers [PBDEs], used as flame retardants, and other pollutants of emerging concern). While concentrations of some of these substances are very low at rural sites, they may be much higher in "hotspots" such as urban 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.

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

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.

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.

Concentrations

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

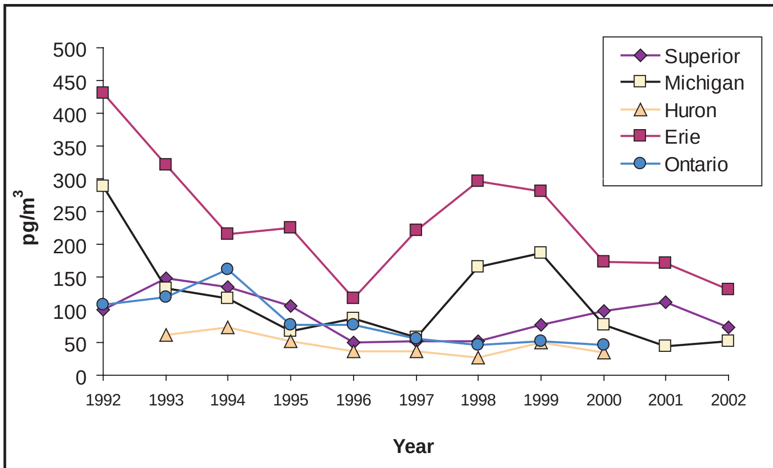

Figure 1. Gas Phase Concentrations of Total PCBs (PCB Suite).
Source: Integrated Atmospheric Deposition Network (IADN) Steering Committee, unpublished, 2004

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 the satellite station in downtown Chicago are about ten times higher than at the more remote master stations. Preliminary data from the new Cleveland station indicate that PCB levels in that city are lower than those in Chicago, but higher than at the master stations.

In general, concentrations of banned or restricted pesticides measured by the IADN (such as hexachlorocyclohexane [α-HCH] and DDT) are decreasing over time in air and precipitation.

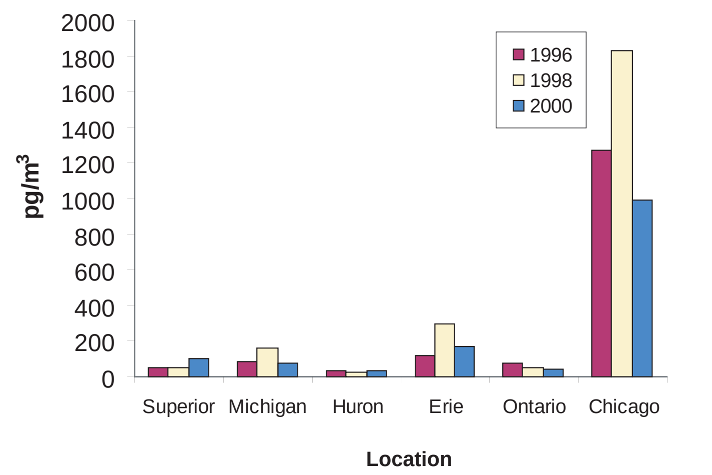

Figure 2. Gas Phase PCB concentrations for rural sites versus Chicago.
Source: Integrated Atmospheric Deposition Network (IADN) Steering Committee, unpublished, 2004

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. The concentrations of BaP (and PAHs in general) are relatively high at Lakes Erie and Ontario, sites near major population centres, and have not changed much over time at all sites. In general, PAH concentrations in Chicago, not shown, are about ten to one hundred times higher than at the master stations.

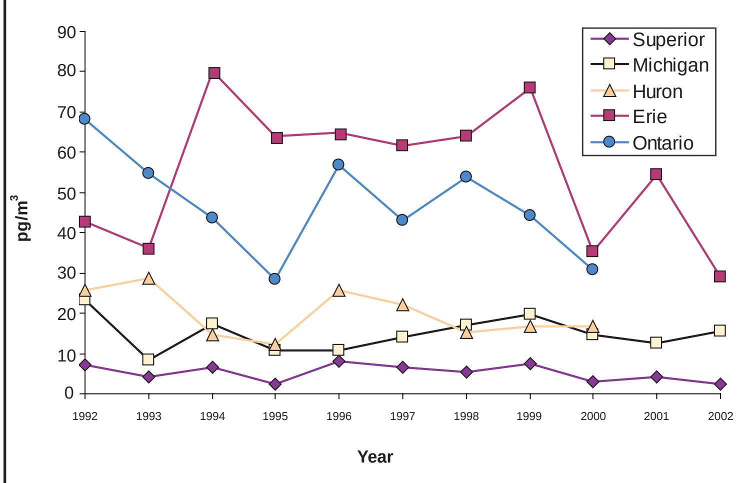

Figure 3. Particulate Concentrations of Benzo(a)pyrene.
Source: Integrated Atmospheric Deposition Network (IADN) Steering Committee, unpublished, 2004

Data from the Canadian Atmospheric Mercury Network (CAMNet) for the IADN stations at Egbert and Point Petre indicate relatively stable total gaseous mercury concentrations between 1997 and 2000 (Blanchard *et al.* 2002).

Concentrations of dioxins and furans have decreased over time (Figure 4) with the largest declines in areas with the highest concentrations (unpublished data, Environment Canada 2004). PBDE data for IADN samples collected during 1997 through

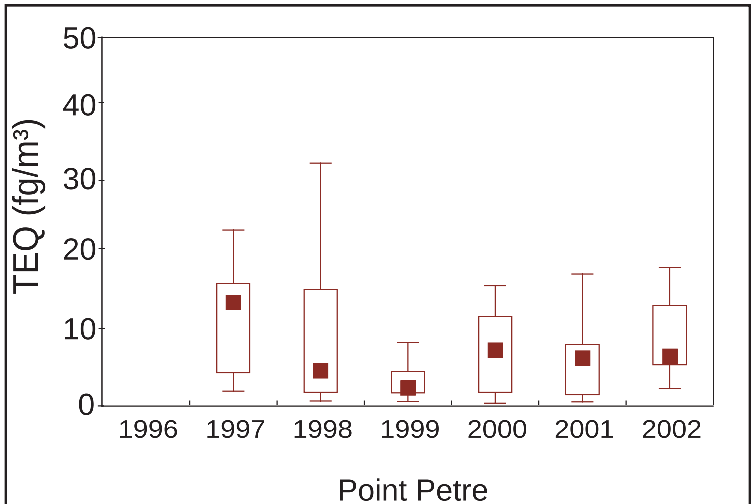

Figure 4. Concentrations of dioxins and furans expressed as TEQ (Toxic Equivalent) in fg/m³ at Point Petre on Lake Ontario.
Source: Environment Canada National Air Pollution Surveillance (NAPS) network, unpublished, 2004

1999 indicate relatively constant levels during that time period (Strandberg *et al.* 2001). However, 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). This implies that air concentrations in the Great Lakes may also be increasing; such a trend would be revealed once more data are collected in the basin.

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 most IADN pollutants. Figure 5 shows net gas exchange loadings for Lake Michigan for PCBs, α-HCH, and γ-HCH (lindane). A bar pointing downward indicates that the net loading is negative, and the compound is volatilizing into the atmosphere. This occurs after the main sources to the air have been cut off and the air becomes "cleaner" relative to the water. The figure shows that the absolute values of the loadings are getting smaller, which indicates that the lake water and the air above it are close to being in equilibrium. PCBs continue the trend of volatilizing out of the lakes but tending towards equilibrium (Blanchard *et al.* 2004). Like concentrations, loadings of banned organochlorine pesticides continue to decline. Current-use pesticides, such as γ-HCH (lindane) and α-endosulfan, are still depositing to the lakes from the atmosphere.

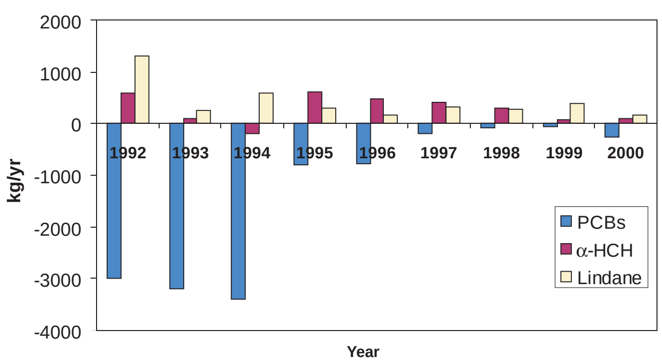

Figure 5. Net Gas Exchange Atmospheric Loadings to Lake Michigan.
Source: Blanchard *et al.*, 2004

In general, for trace metals wet deposition is always more important than dry deposition and there is a lack of trend data over time. This is consistent with continuing emissions of trace metals.

A report on the atmospheric loadings of these compounds to the Great Lakes has recently been published for data through 2000. It is 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. 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 further reduced.

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. Actions are being taken in the United States and in Europe to reduce use of certain types of PBDEs. IADN is starting to monitor PBDEs. Thus, in the future, decreases in levels of these chemicals may be observed.

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). Controls on the emissions of combustion systems, such as 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 "levelling-off" 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 the Persistent Bioaccumulative Toxics (PBT) Program of the U.S. Environmental Protection Agency (USEPA) 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 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. Such work will help prioritize PCB disposal and remediation projects in order to further reduce atmospheric deposition. 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 nation-wide 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.

Voluntary pollution prevention activities, technology-based pollution controls, and chemical substitution (for pesticides 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 toxics 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. Further funding is needed to implement mercury monitoring for the U.S. side of IADN. Additional urban monitoring is also needed to better characterize atmospheric deposition to the Great Lakes.

Acknowledgments
Author: This report was prepared on behalf of the IADN Steering Committee by Melissa Hulting, IADN Program Manager, U.S. Environmental Protection Agency, Great Lakes National Program Office.

IADN Contacts
IADN Principal Investigator, Air Quality Research Branch, Environment Canada, 4905 Dufferin Street, Toronto, ON, M3H 5T4.

IADN Program Manager, Great Lakes National Program Office, U.S. Environmental Protection Agency, 77 West Jackson Boulevard (G-17J), Chicago, IL, 60604

Sources
Blanchard, P., Audette, C.V., Hulting, M.L., Basu, I., Brice, K.A., Chan, C.H., Dryfhout-Clark, H., Froude, F., Hites, R.A., and Neilson, M. 2004. *Atmospheric Deposition of Toxic Substances to the Great Lakes: IADN Results Through 2000*. U.S. Environmental Protection Agency and Environment Canada. Public Works and Government Services Canada En56-156/2000-1E, EPA 905-R-04-900.

Blanchard, P., Froude, F.A., Martin, J.B., Dryfhout-Clark, H., and Woods, J.T. 2002. Four Years of Continuous Total Gaseous Mercury (TGM) Measurements at Sites in Ontario, Canada. *Atmospheric Environment* 36(23):3735-43.

Environment Canada and U.S. Environmental Protection Agency. 2003. The Great Lakes Binational Toxics Strategy 2002 Annual Progress Report. http://binational.net/bns/2002/index.html *last accessed 11.03.05.*

Hafner, W.D., and Hites, R.A. 2003. Potential Sources of Pesticides, PCBs, and PAHs to the Atmosphere of the Great Lakes. *Environmental Science and Technology* 37(17):3764-3773.

Hites, R.A. 2004. Polybrominated Diphenyl Ethers in the Environment and in People: A Meta-Analysis of Concentrations. *Environmental Science and Technology* 38(4):945-956.

Ma, J., Hung, H., and Blanchard, P. 2004a. How Do Climate Fluctuations Affect Persistent Organic Pollutant Distribution in North America? Evidence from a Decade of Air Monitoring. *Environmental Science and Technology* 38(9):2538-2543

Ma, J., Daggupaty, S., Harner, T., Blanchard, P., and Waite, D. 2004b. Impacts of Lindane Usage in the Canadian Prairies on the Great Lakes Ecosystem: 2. Modeled Fluxes and Loadings to the Great Lakes. *Environmental Science and Technology* 38(4):984-990.

Strandberg, B., Dodder, N.G., Basu, I., and Hites, R.A. 2001. Concentrations and Spatial Variations of Polybrominated Diphenyl Ethers and Other Organohalogen Compounds in Great Lakes Air. *Environmental Science and Technology* 35(6):1078-1083.

Totten, L.A., Brunciak, P.A., Gigliotti, C.L., Dachs, J., Glenn, T.R., IV, Nelson, E.D., and Eisenreich, S.J. 2001. Dynamic Air-Water Exchange of Polychlorinated Biphenyls in the New York-New Jersey Harbor Estuary. *Environmental Science and Technology* 35(19):3834-3840.

Wethington, D.M., III, and Hornbuckle, K.C. 2005. Milwaukee, WI as a Source of Atmospheric PCBs to Lake Michigan. *Environmental Science and Technology* 39(1):57-63.

Toxic Chemical Concentrations in Offshore Waters

Indicator #118

Assessment: Mixed, Improving

Purpose

- To assess the concentration of priority toxic chemicals in offshore waters;
- To infer the potential for impacts on the health of the Great Lakes aquatic ecosystem by comparison to criteria for the protection of aquatic life and human health; and
- To infer progress toward virtual elimination of toxic substances from the Great Lakes basin.

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 (Great Lakes Water Quality Agreement, Article III(d), United States and Canada 1987).

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) and Chapter 9 of the Great Lakes Binational Toxics Strategy 2002 Progress Report.

Organochlorine chemicals, several of which are on various “critical pollutant” lists, have and are still declining in the Great Lakes in response to management efforts. Spatial concentration patterns illustrate the ubiquitous nature of some, or the influence of localized source(s) of others.

An example of an organochlorine chemical with more widespread distribution is dieldrin. Concentrations of dieldrin in the Great Lakes continue to decrease (Marvin *et al*., 2004). Concentrations of dieldrin in the Niagara River have decreased by more than 70% between 1986 and 2000/01 (Williams and O’Shea 2003).

Hexachlorobenzene (HCB), octachlorostyrene, and mirex exemplify organochlorine chemicals whose presence is due to historical, localized sources. Consequently, their occurrence in the environment is isolated to specific locations in the Great Lakes basin. Concentrations of all three in the Niagara River have decreased by more than 70% between 1986 and 2000/01 (Williams and O’Shea 2003).

Pressures

Management efforts to control inputs of organochlorine chemicals have resulted in decreasing concentrations in the Great Lakes. Historical sources for some, however, still appear to affect ambient concentrations in the environment. Chemicals such as endocrine disrupting chemicals, in-use pesticides, and pharmaceuticals are emerging issues.

Management Implications

The Great Lakes Binational Toxics Strategy efforts need to be maintained to identify and track the remaining sources of toxic chemicals and to explore opportunities to accelerate their elimination.

Targeted monitoring to identify and track down local sources should be considered for those chemicals whose distribution suggests localized influences.

Acknowledgments

Author: Scott Painter, Environment Canada, Burlington, ON.

Sources

Great Lakes Binational Toxics Strategy. 2002. *2002 Progress Report*. Environment Canada and U.S. Environmental Protection Agency.

Marvin, C., Painter, S., Williams, D., Richardson, V., Rossmann, R., and Van Hoof, P. 2004. Spatial and temporal trends in surface water and sediment contamination in the Laurentian Great Lakes. *Environmental Pollution* 129(2004):131-144.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington. http://www.ijc.org/rel/agree/quality.html, last accessed October 4, 2005.

Williams, D.J., and O’Shea, M.L. 2003. *Niagara River Toxics Management Plan (NRTMP) Progress Report and Work Plan.* Prepared for the Niagara River Secretariat. Environment Canada, U.S. Environmental Protection Agency, Ontario Ministry of Environment and New York State Department of Environmental Conservation.

Authors’ Commentary

Beginning in 1986, Environment Canada has conducted toxic contaminant monitoring in the shared waters of the Great Lakes. In 2004, U.S. Environmental Protection Agency (USEPA) initiated a monitoring program for toxics in offshore waters. USEPA’s analyte list includes PCBs, organochlorine pesticides, toxaphene, dioxins/furans, PBDEs, selected PAHs, mercury, PFOS (perfluorooctanyl sulfonate) and PFOA (perfluorooctanoic acid). Environment Canada and USEPA are discussing their two programs with basin-wide reporting possibilities for the SOLEC 2006 report. An agreed upon approach for summarizing and reporting the indicator will also be required given that many chemicals and locations have unique stories to tell.

Concentrations of Contaminants in Sediment Cores

Indicator #119

Assessment: Mixed, Improving

Purpose

- To infer potential harm to aquatic ecosystems from contaminated sediments by comparing contaminant concentrations to available sediment quality guidelines; and
- 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.

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 from the metrics used in the recently approved Canadian Water Quality Index. The SQI 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 modified SQI was also developed, using only the scope and amplitude elements, which provides an SQI score per site, but with no grouping of sites. 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).

Application of SQI

Environment Canada initiated a comprehensive sediment contaminant survey of the open waters of the Great Lakes in 1997. Data for 34 chemicals with guidelines were available for Lakes Erie and Ontario. 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 (Table 1). Spatial trends in sediment quality in Lakes Erie and Ontario reflected overall trends for individual contaminant classes such as mercury and polychlorinated biphenyls (PCBs). The spatial representation of sediment quality using the individual site SQI scores as well as the area SQI scores represent the individual spatial patterns in the 34 chemicals.

Lake and Basin	SQI
Erie	
Western Basin	85
Central Basin	86
Eastern Basin	95
Ontario	
Niagara	67
Mississauga	66
Rochester	70
Kingston	87

Table 1. Sediment Quality Index (SQI) for Lakes Erie and Ontario.
Source: Painter *et al*. (2001) and Marvin *et al*. (2002)

Environment Canada and U.S. Environmental Protection Agency (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.

The SQI was applied to 5 priority AOCs for which the USEPA has collected sediment data. Table 2 contains the SQI scores for these 5 priority AOCs. SQI scores for these AOCs are based on the results of available chemical analysis for surficial sediment concentrations only. Future sediment data collected in AOCs at these sites can be compared to current SQI scores to determine trends in sediment contamination.

Pressures

Management efforts to control inputs of historical contaminants

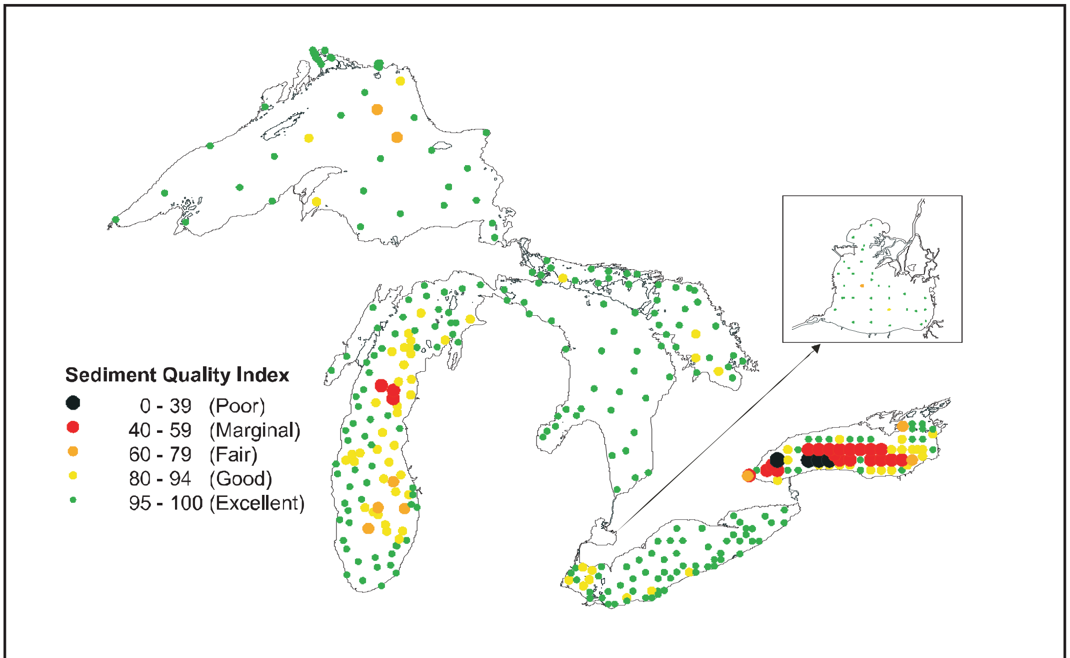

Figure 1. Site Sediment Quality Index (SQI) based on lead, zinc, copper, cadmium and mercury. Source: Chris Marvin, Environment Canada, National Water Research Institute (1997-2001 data for all lakes except Michigan); and Ronald Rossmann, U.S. Environmental Protection Agency (1994-1996 data for Lake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

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, e.g., polybrominated diphenyl ethers, PDBE), polychlorinated naphthalenes (PCNs), polychlorinated alkanes (PCAs), endocrine disrupting chemicals, in-use pesticides and pharmaceuticals and personal care products 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. Elevated levels of HBCD were associated with heavily urbanized/industrialized areas of the watershed, indicating that large urban centres can act as diffuse sources of contaminants. The HBCD distribution differs somewhat from PCBs, which are primarily associated with areas of contaminated sediment resulting from historical industrial activities including steel manufacturing and chlor-alkali production.

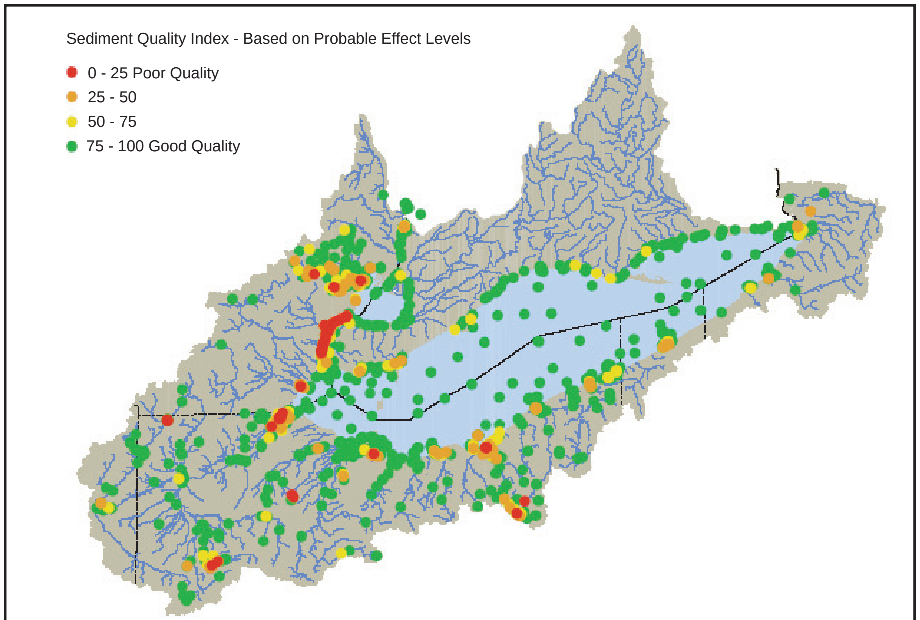

Figure 2. Sediment Quality Index (SQI) for the Lake Erie-Lake St. Clair drainages. More detailed information on contaminants in sediments in the Lake Erie-Lake St. Clair drainages has been reported by the USGS (2000). Source: Dan Button, U.S. Geological Survey

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 localize sources.

Acknowledgments

Authors: Scott Painter, Environment Canada, Burlington, ON; and Chris Marvin, Environment Canada, Burlington, ON.

Sources

Canadian Council of Ministers of the Environment (CCME). 1999, updated 2001. *Canadian Environmental Quality Guidelines.* Canadian Council of Ministers of the Environment. Winnipeg, MB, Canada.

Site	SQI Score
Grand Calumet River/Indiana Harbor, IN	24.5
Saginaw River and Harbor, MI	57.5
Buffalo River, NY	93.2
Sheboygan River and Harbor, WI	29.4
Ashtabula River and Harbor, OH	36.4

Table 2. SQI scores for 5 U.S. priority AOC sediment assessments, data collected from 1987-1989.
Source: Scott Cieniawski, USEPA

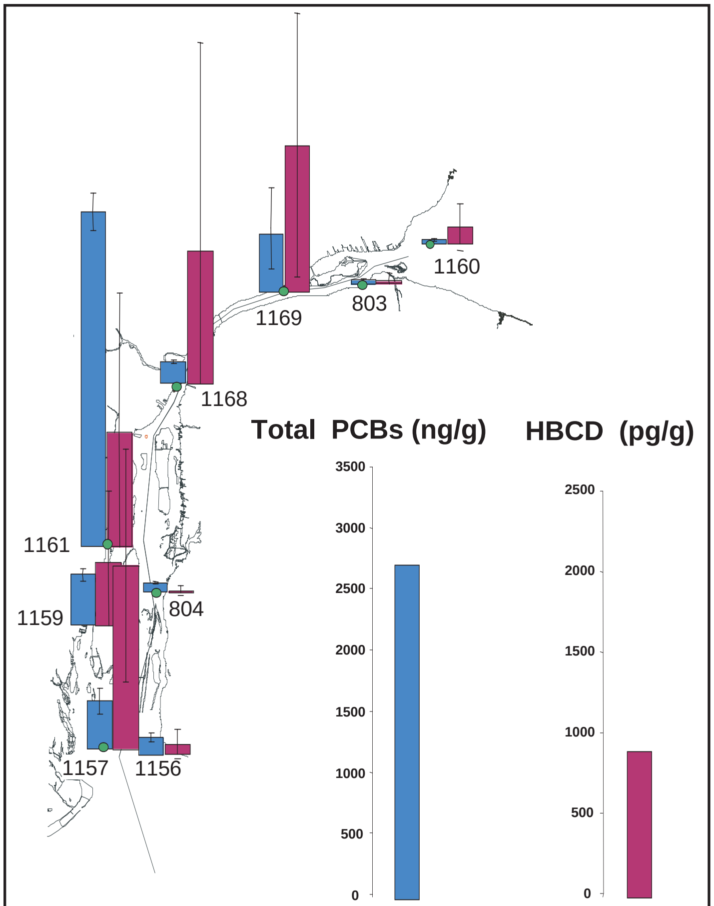

Figure 3. Distribution of hexabromocyclododecane (HBCD) and PCBs in suspended sediments in the Detroit River.
Source: Chris Marvin, Environment Canada, National Water Research Institute

Grapentine, L., Marvin, C., and Painter, S. 2002. Development and evaluation of a sediment quality index for the Great Lakes and associated Areas of Concern. *Human and Ecological Risk Assess.* 8(7):1549-1567.

Marvin, C.H., Charlton, M.N., Reiner, E.J., Kolic, T., MacPherson, K., Stern, G.A., Braekevelt, E., Estenik, J.F., Thiessen, L., and Painter, S. 2002. Surficial sediment contamination in Lakes Erie and Ontario: A comparative analysis. *J. Great Lakes Res.* 28(3):437-450.
Marvin, C., Grapentine, L., and Painter, S. 2004. Application of a sediment quality index to the lower Laurentian Great Lakes. *Environ. Monit. Assess.* 91:1-16.

Painter, S., Marvin, C., Rosa, F., Reynoldson, T.B., Charlton, M.N., Fox, M., Thiessen, P.A.L., and Estenik, J.F. 2001. Sediment contamination in Lake Erie: A 25-year retrospective analysis. *J. Great Lakes Res.* 27(4):434-448.

Persaud, D., Jaagumagi, R., and Hayton, A. 1992. *Guidelines for the protection and management of aquatic sediment quality in Ontario.* Water Resources Branch, Ontario Ministry of the Environment and Energy. June 1992.

Rossman, R., U.S. Environmental Protection Agency (USEPA), Office of Research and Development-National Health, and Environmental Effects Research Laboratory-Mid-Continent Ecology Division. 1994-1996. Unpublished data.

U.S. Geological Survey (USGS). 2000. *Areal distribution and concentrations of contaminants of concern in surficial streambed and lakebed sediments, Lake Erie – Lake St. Clair drainages, 1990-97.* Water Resources Investigations Report 00-4200.

Authors' Commentary

Work towards application of the SQI to all lakes, including Lake St. Clair, is ongoing. Data for lead, zinc, copper, cadmium and mercury have been collated.

Environment Canada, Ontario Ministry of the Environment, and the USEPA need to determine the availability of historical and current sediment quality data (both nearshore and open lake) to facilitate both spatial analysis and to confirm the availability of index sites to examine temporal trends.

Continued exploration and refinement of the SQI approach should be explored, especially the issue of agreement on guidelines to use in implementing the SQI and an appropriate classification scheme.

Contaminants in Whole Fish

Indicator #121

Assessment: Mixed, Improving

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 the Canadian Department of Fisheries and Oceans (DFO) through the Fish Contaminants Surveillance Program. DFO reports annually on contaminant burdens in similarly aged lake trout (4+ - 6+ year range) and 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). 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 specific characteristics of the substances involved and the biological composition of the fish community.

Status and Trends of Contaminants in Whole 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. The GLWQA criterion for PCBs states that, “the concentration of total polychlorinated biphenyls in fish tissues (whole fish, calculated on a wet weight basis), should not exceed 0.1 micrograms per gram for the protection of birds and animals which consume fish.” The GLWQA criterion for DDT and metabolites states that, “the sum of the concentrations of DDT and its metabolites in whole fish should not exceed 1.0 microgram per gram (wet weight basis) for the protection of fish-consuming aquatic birds.” The GLWQA criteria for mercury states that, “the concentration of total mercury in whole fish should not exceed 0.5 micrograms per gram (wet weight basis) to protect aquatic life and fish-consuming birds.” Table 1 lists species and locations where GLWQA criteria are exceeded based on current data collected by DFO and GLNPO. DFO collects lake trout and smelt from all lakes and walleye from Lake Erie. GLNPO collects lake trout from all lakes except Lake Erie, where walleye are collected.

Lake	Species	Hg *	PCB*, **	ΣDDT***	ΣDDT****
Ontario	Smelt	√	X*	√	
	Lake Trout	No Data	X		
Erie	Smelt	√	√*	√	
	Lake Trout	No Data	X*	√	
	Walleye	√	X?	√	√
Huron	Smelt	√	√*	√	
	Lake Trout	No Data	X		
Superior	Smelt	√	√*	√	
	Lake Trout	No Data	X		
Michigan	Lake Trout		X		

*Data Source: DFO Fish Contaminants Surveillance Program (2002-2003)
** Data Source: GLNPO Great Lakes Fish Monitoring Program (1999-2000)
***ΣDDT = (p,p' DDD + p,p'DDT + o,p'DDT + p,p' DDE) - DFO
****ΣDDT = (p,p' DDD + p,p'DDT + p,p' DDE) - GLNPO
√ - Below Agreement Objective
X - Exceeds Agreement Objective

Table 1. Fish species and locations where GLWQA specific objectives are currently exceeded.

In the lake-by-lake discussion that follows, the expression “ΣDDT” refers to the sum of concentrations of DDT and the breakdown products as listed in Table 1. The summations are slightly different for GLNPO and DFO data.

Lake Michigan

The concentrations of ΣDDT and total PCBs in lake trout from Lake Michigan (Figure 1 and Figure 3 respectively) consistently declined through 2000. The observed concentrations of Σ DDT have remained below the GLWQA criteria since 1986. Concentrations of total PCBs, however, remain above the GLWQA criteria.

Lake Superior

ΣDDT: Both GLNPO and DFO lake trout data (Figure 1 and

Figure 2, respectively) display a general fluctuation in concentrations from year to year, but with a recent increase. The increased concentration observed by GLNPO in the 2000 samples, compared to the 1998 samples, may be related to a change in collection sites. The concentrations observed by DFO in 2002, however, were within the range reported from 1996 to 2002. Concentrations of ΣDDT in smelt have declined steadily from 1998 through 2002 (Figure 5). GLNPO-observed concentrations of ΣDDT in Lake Superior lake trout have remained below the GLWQA criteria since 1989, and DFO-observed lake trout and smelt concentrations have never been above the GLWQA criteria.

Total PCBs: GLNPO lake trout data show annual fluctuations in average PCB concentrations through the early 1980s, but since then the variability between years has been reduced (Figure 3). DFO lake trout data show very little change in the mean PCB concentrations from 1996 to the present (Figure 4). DFO smelt data show a steady decline in PCB concentrations from 1985 through 2002 (Figure 6). The 2002 concentration of PCBs in smelt was the lowest recorded since DFO began monitoring Lake Superior in 1981. Observed concentrations of total PCBs in both GLNPO and DFO Lake Superior lake trout collections remain above the GLWQA criteria, while PCB concentrations in smelt have been consistently below GLWQA criteria since 1993.

Mercury: The concentrations of mercury in smelt have steadily declined through 2002, when the lowest concentration since 1981 was observed, and they have consistently remained below the GLWQA criteria.

Lake Huron

ΣDDT: Both GLNPO and DFO lake trout data show a general decline in Σ DDT concentrations over time (Figure 1 and Figure 2). Both programs observed large fluctuations in ΣDDT concentrations in the early years of analysis followed recently by a relatively consistent year-to-year decline. Likewise, ΣDDT concentrations in Lake Huron smelt also fluctuated between years, but they exhibit a recent downward trend (Figure 5). GLNPO- and DFO-observed concentrations of ΣDDT in Lake Huron lake trout have consistently remained at or below the GLWQA criteria since 1988 and 1984, respectively. ΣDDT concentrations in Lake Huron smelt have never been observed to be above GLWQA criteria.

Total PCBs: Both GLNPO and DFO lake trout data show a general decline in concentrations of PCBs over time (Figure 3 and Figure 4). Concentrations in 2003 DFO lake trout samples were the second lowest ever recorded for the program, which was initiated in 1980. PCB concentrations in smelt fluctuated considerably from 1979 to 2003 (Figure 6). Total PCB concentrations in lake trout observed by both GLNPO and DFO remain above the GLWQA criteria. PCB concentrations in smelt have consistently remained below GLWQA criteria since 1997.

Mercury: Mercury concentrations in smelt have fluctuated considerably over the period between 1979 and 2003 (Figure 7). Smelt collected in 2003 had the highest lake-wide concentration recorded since 1984, but mercury levels in Lake Huron smelt have never been observed to be above the GLWQA criteria.

Lake Erie

Σ DDT: All monitored species in Lake Erie display a similar pattern of a general decline in ΣDDT concentrations (Figure 1, Figure 2, Figure 5 and Figure 9). In each species, a moderate increase of ΣDDT concentrations was observed in the mid- to late-1980s followed by a sharp decline in ΣDDT concentrations. The increase in ΣDDT levels corresponds to the period of the rapid proliferation of the zebra mussel population within Lake Erie. Both GLNPO and DFO walleye data follow the same pattern (Figure 1 and Figure 9). Walleye collected in Lake Erie represent conditions primarily in the western and central basins of the lake because they migrate between these basins at points during each year. DFO lake trout data (Figure 2) and smelt data (Figure 5) also exhibit fluctuating concentrations over time, although the limited number of trout samples available makes rigorous temporal trend assessment difficult. Lake trout, however, primarily represent conditions in the eastern basin of the lake as their movement is restricted by generally higher water temperatures prominent outside this basin. Concentrations of Σ DDT in Lake Erie walleye, lake trout and smelt have never been observed to be above GLWQA criteria.

Total PCBs: Total PCB concentrations in Lake Erie fish were also affected by the introduction of zebra mussels, leading to a general increase in organic contaminant concentrations. Walleye analyzed by GLNPO exhibited a period of increased PCB concentration from the late 1980s through the early 1990s followed by sharp declines in total PCB concentration (Figure 3). Walleye analyzed by DFO exhibited a similar pattern, i.e., a period of annual increases from 1985 through 1993 followed by a decline in PCB concentration and then relatively steady concentrations over the past 4 years through 2003 (Figure 10). DFO lake trout data show a decrease in PCB concentration between 1990 and 2001, followed by a slight increase in concentration through to 2003 (Figure 4). PCB concentrations in smelt from Lake Erie were quite variable but declined strongly after a large peak in 1990 (Figure 6). Concentrations of PCBs in Lake Erie walleye and lake trout are currently above GLWQA criteria, but PCB concentrations in Lake Erie smelt have never been observed to be above GLWQA criteria.

Mercury: After a period of rapid decline from 1977 through 1983, mercury concentrations in Lake Erie walleye have remained steady (Figure 11). After 1996, the frequency of annual measurements of mercury burdens in walleye by DFO was reduced. The mean of two recent measurements made in 1999 and 2003 was ~ 15% greater than the 5 year mean of the period 1992 through 1996. Concentrations of mercury in smelt collected in 2002 had the highest concentrations reported since the whole lake survey was initiated in 1977 (Figure 7). The 2003 mercury concentrations, however, were the 2nd lowest. The concentration of mercury in Lake Erie smelt is below GLWQA criteria.

Lake Ontario

ΣDDT: Both GLNPO and DFO lake trout data show a period of small fluctuations in ΣDDT concentrations through the mid-1990s (Figure 1 and Figure 2). Both programs identify a declining trend in Σ DDT concentration from 1994 through the present. ΣDDT concentrations in smelt consistently declined between 1998 and 2002 (Figure 5). There was only a slight increase reported in 2003 smelt. ΣDDT in Lake Ontario lake trout have consistently been below the GLWQA criteria since 1995, and mercury concentrations in Lake Ontario smelt have never been observed to be above GLWQA criteria.

Total PCBs: Both GLNPO and DFO lake trout data show a consistent decline in PCB concentrations through the present with very little change in concentration since the late 1990s (Figure 3 and Figure 4). PCB concentrations in smelt have declined greatly from their peak in 1988, and there were minor declines in PCB concentrations between 1999 and 2003 (Figure 6). Concentrations of PCBs in Lake Ontario lake trout and smelt are above the GLWQA criteria.

Mercury: Very little change has been observed in the annual mean mercury levels reported for smelt since the mid-1980s (Figure 7). However, the 2003 level was the highest recorded since 1984. Concentrations of mercury in Lake Ontario smelt have never been observed to be above the GLWQA criteria.

Other Contaminants of Emerging Interest:

There are a number of potentially harmful contaminants reported in Great Lakes fish. The foremost is the group of brominated flame retardants (BFRs) that have been reported in fish tissues for several years throughout the Great Lakes basin. Retrospective analyses of archived samples confirm the continuing increase in concentrations of polychlorinated brominated diphenyl ethers (PBDE) in lake trout from Lake Ontario (Figure 12). Concentrations have increased exponentially from 0.54 ng/g in 1978 to 190 ng/g wet weight in whole fish samples collected in 2002 (Whittle *et al.,* 2004).

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.

Researchers are also discovering that pharmaceuticals, such as endocrine disruptors, may be a factor in declining populations of some fish species. While more research is conducted on this topic, management agencies at all levels of government could begin identifying options to reduce or eliminate future loadings of pharmaceuticals to the Great Lakes.

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 chemicals 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.

Lake	Contaminant	Species	Highest Recorded Concentration		Most Recently Measured Conc'n		% of Highest Recorded Concentration
			Year	Value (µg/g)	Year	Value (µg/g)	
Superior	ΣDDT	Lake Trout	1977	1.2	2000	0.567	47%
	Total PCBs	Lake Trout	1980	1.89	2000	0.784	41%
Michigan	ΣDDT	Lake Trout	1970	19.19	2000	1.056	6%
	Total PCBs	Lake Trout	1974	22.91	2000	1.614	7%
Huron	ΣDDT	Lake Trout	1979	3	2000	0.557	19%
	Total PCBs	Lake Trout	1979	3.66	2000	0.779	21%
Erie	ΣDDT	Walleye	1977	0.51	2000	0.085	17%
	Total PCBs	Walleye	1977	2.64	2000	1.241	47%
Ontario	ΣDDT	Lake Trout	1977	1.93	2000	0.864	45%
	Total PCBs	Lake Trout	1977	8.33	2000	1.174	14%

*All concentrations based on whole fish samples

Table 2. Percent Change in Total PCBs, and ΣDDT, Concentrations for GLNPO Fish Collections (Size-Lake Trout: 600-700mm, Walleye: 450-550mm).
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office, Great Lakes Fish Monitoring Program

Acknowledgments
Authors: Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office;
D. Michael Whittle, Department of Fisheries and Oceans, Great Lakes Laboratory for Fisheries & Aquatic Sciences;
Michael J. Keir, Department of Fisheries and Oceans, Great Lakes Laboratory for Fisheries & Aquatic Sciences; and
J. Fraser Gorrie, Bio-Software Environmental Data.

Sources
Cook, P.M., Robbins, J.A., Endicott, D.D., Lodge, K.B., Guiney, P.D., Walker, M.K, Zabel, E.W., and Peterson, R.E. 2003. Effects of Aryl Hydrocarbon Receptor-Mediated Early Life Stage Toxicity on Lake Trout Populations in Lake Ontario during the 20th Century. *Environ. Sci. Technol.*37(17):3878-3884.

Martin, J.W., Whittle, D.M., Muir, D.C.G., and Mabury, S.A. 2004. Perfluoroalkyl Contaminants in the Lake Ontario Food Web. *Environ. Sci. Technol*. 38(20):5379-5385.

Stock, N.L., Bonin J., Whittle, D.M., Muir, D.C.G., and Mabury, S.A. 2003. *Perfluoronated Acids in the Great Lakes*. SETAC Europe 13th Annual Meeting, Hamburg, Germany.

Tomy, G.T., Budakowski, W., Halldorson T., Whittle, D.M., Keir, M., Marvin, C., MacInnis, G., and Alaee, M. 2004. Biomagnification of ? and ?-Hexabomocyclododecane in a Lake Ontario Food Web. *Environ. Sci. Technol.* 38:2298-2303.
United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington. http://www.ijc.org/rel/agree/quality.html.

Whittle, D.M., MacEachen, D.C., Sergeant, D.B., Keir, M.J., and Moles, M.D. *Food Web Biomagnification of Brominated Diphenyl Ethers in Two Great Lakes Fish Communities*, pp 83-86. 3rd International Workshop on Brominated Flame Retardants, Toronto, Ontario.

Lake	Contaminant	Species	Highest Recorded Concentration		Most Recently Measured Conc'n		% of Highest Recorded Concentration
			Year	Value (µg/g)	Year	Value (µg/g)	
Superior	ΣDDT	Lake Trout	1981	0.36	2002	0.1	28%
		Smelt	1982	0.09	2002	0.01	12%
	Total PCBs	Lake Trout	1988	1.91	2002	0.33	17%
		Smelt	1985	0.3	2002	0.03	10%
	Mercury	Smelt	1981	0.1	2003	0.02	20%
Huron	ΣDDT	Lake Trout	1981	1.1	2003	0.16	15%
		Smelt	1982	0.12	2003	0.02	17%
	Total PCBs	Lake Trout	1982	2.52	2003	0.43	17%
		Smelt	1982	0.29	2003	0.03	10%
	Mercury	Smelt	1980	0.07	2003	0.05	74%
Erie	ΣDDT	Walleye	1977	0.9	2003	0.06	7%
		Lake Trout	1989	0.83	2003	0.07	8%
		Smelt	1980	0.12	2003	0.01	8%
	Total PCBs	Walleye	1979	3.11	2003	1.08	35%
		Lake Trout	1990	1.75	2003	0.7	40%
		Smelt	1990	0.76	2003	0.08	11%
	Mercury	Walleye	1977	0.37	2003	0.12	32%
		Smelt	2002	0.05	2003	0.02	40%
Ontario	ΣDDT	Lake Trout	1977	4.54	2003	0.36	8%
		Smelt	1977	0.6	2003	0.06	10%
	Total PCBs	Lake Trout	1977	9.05	2003	1.17	13%
		Smelt	1988	2.15	2003	0.18	8%
	Mercury	Smelt	1982	0.09	2003	0.04	44%

*All concentrations based on whole fish samples

Table 3. Percent change in total PCBs, ΣDDT, and mercury concentrations for DFO fish collections (Age 4+ - 6+ range).
Source: Canadian Department of Fisheries and Oceans (DFO), Fish Contaminants Surveillance Program

Species	ΣHBCD (α+γ isomers) (ng/g wet wt ± S.E.)
Lake Trout	1.68 ± 0.67
Sculpin	0.45 ± 0.10
Smelt	0.27 ± 0.03
Alewife	0.13 ± 0.02
Mysis	0.07 ± 0.02
Diporeia	0.08 ± 0.01
Plankton	0.02 ± 0.01

Table 4. Lake Ontario food web bioaccumulation of HBDC isomers.
Source: Tomy *et al.* 2004

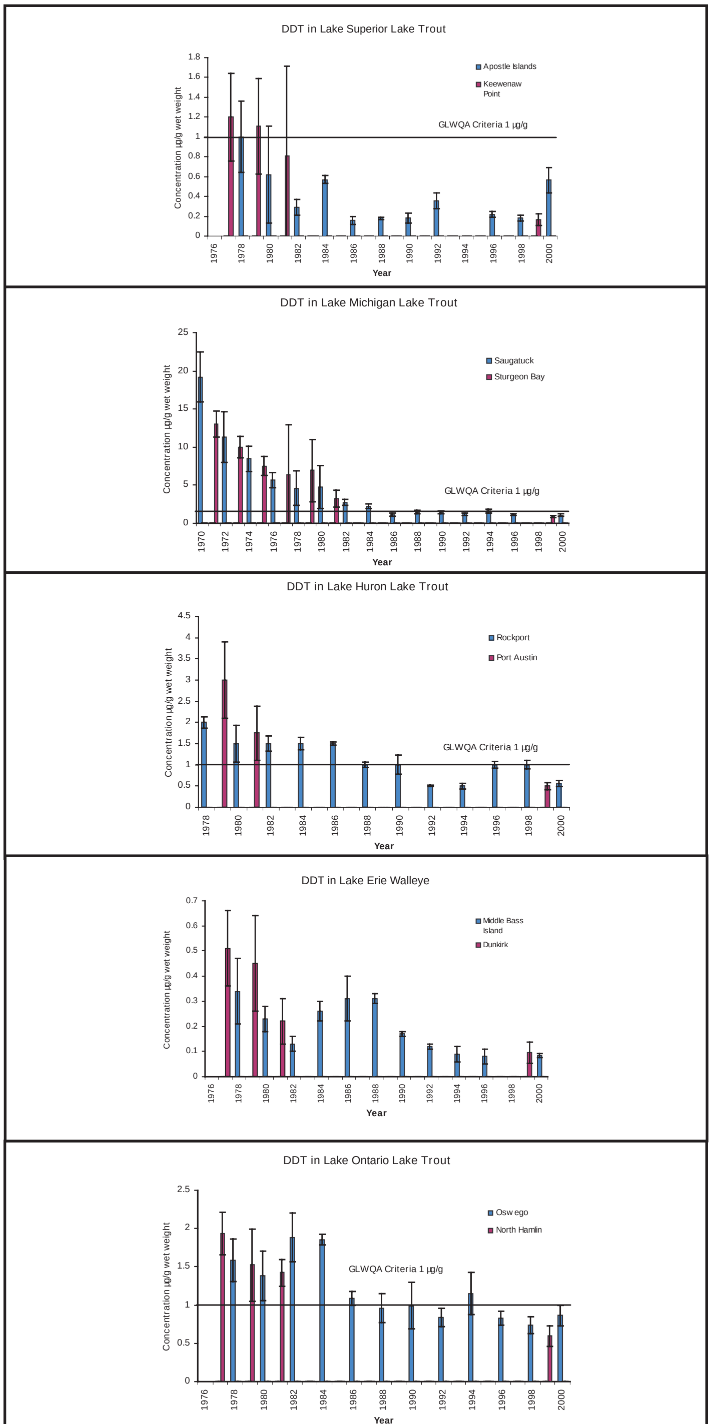

Figure 1. DDT levels in whole Lake Trout (Walleye in Lake Erie), 1972-2000 µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range. Note the different scales on Y axis between lakes.
Source: U.S. Environmental Protection Agency

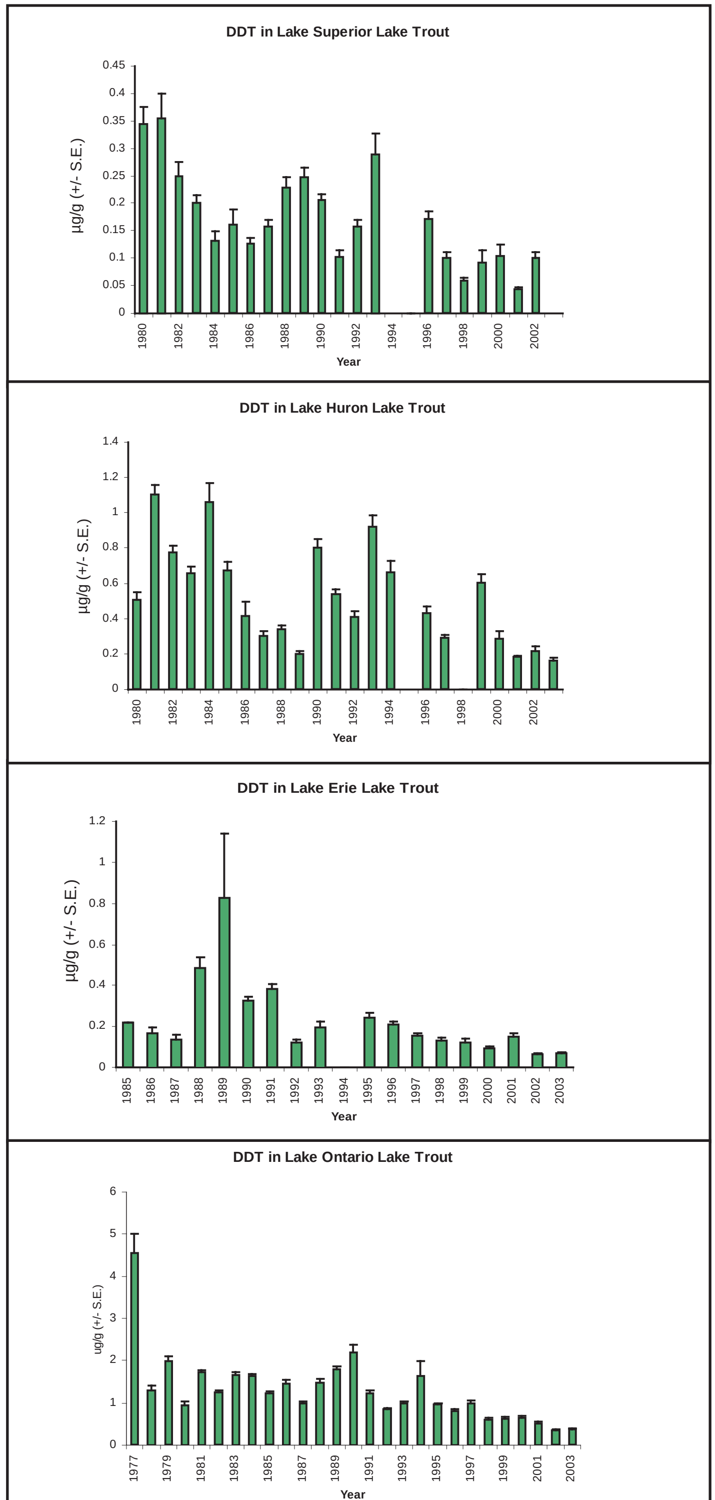

Figure 2. Total DDT levels in whole Lake Trout, 1977-2003. Canadian data µg/g wet weight +/- S.E., ages 4-6 years. Note the different scales between lakes.
Source: Department of Fisheries and Oceans Canada

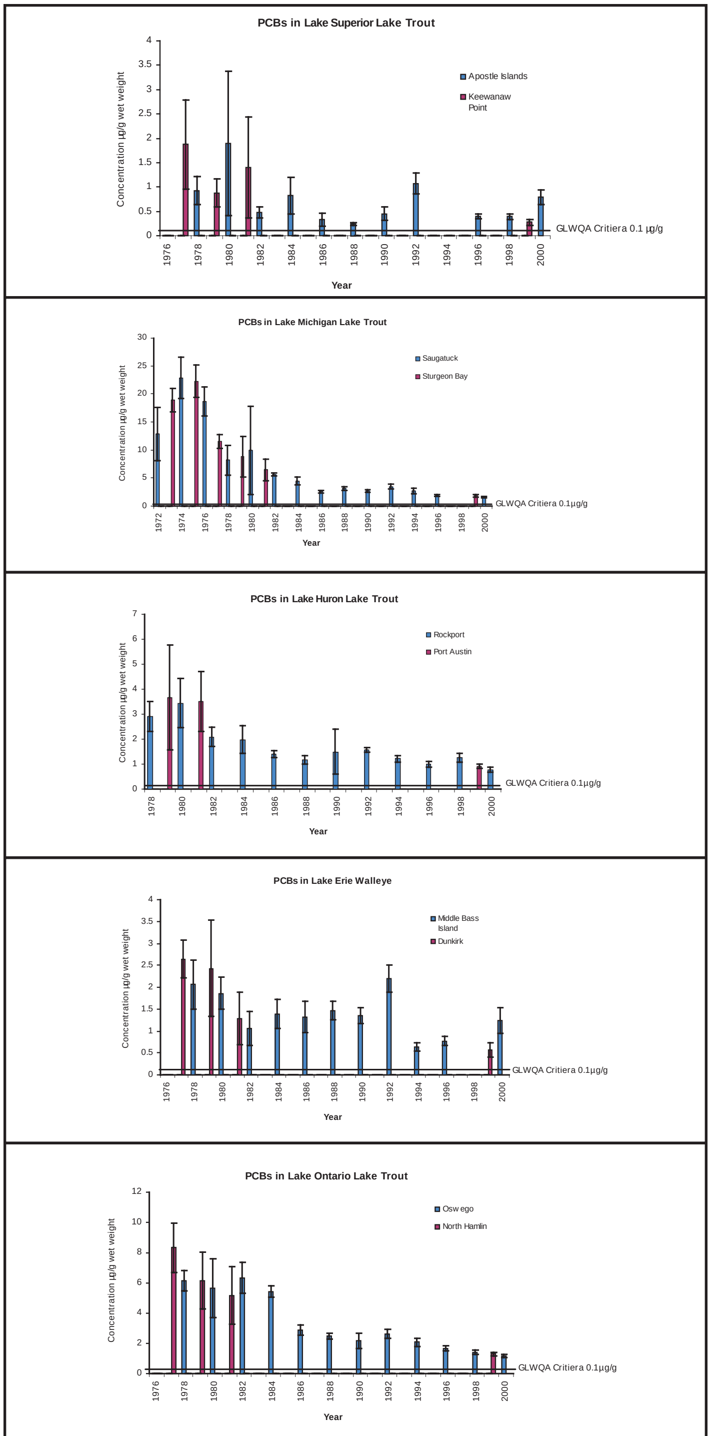

Figure 3. Total PCB levels in whole Lake Trout (Walleye in Lake Erie), 1972-2000. µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range. Note the different scales on Y axis between lakes.
Source: U.S. Environmental Protection Agency

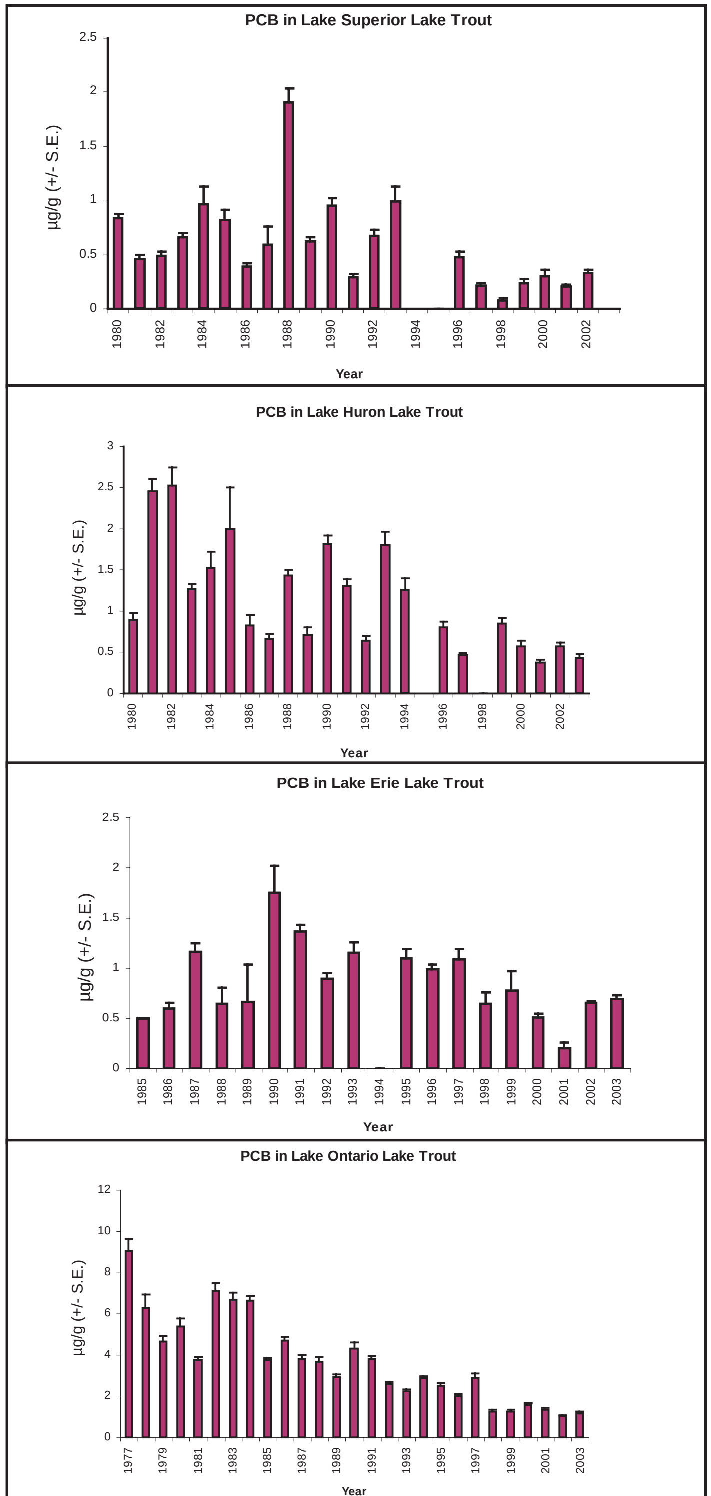

Figure 4. Total PCB levels in whole Lake Trout, 1977-2003. Canadian data µg/g wet weight +/- S.E., ages 4-6 years. Note the different scales between lakes.
Source: Department of Fisheries and Oceans Canada

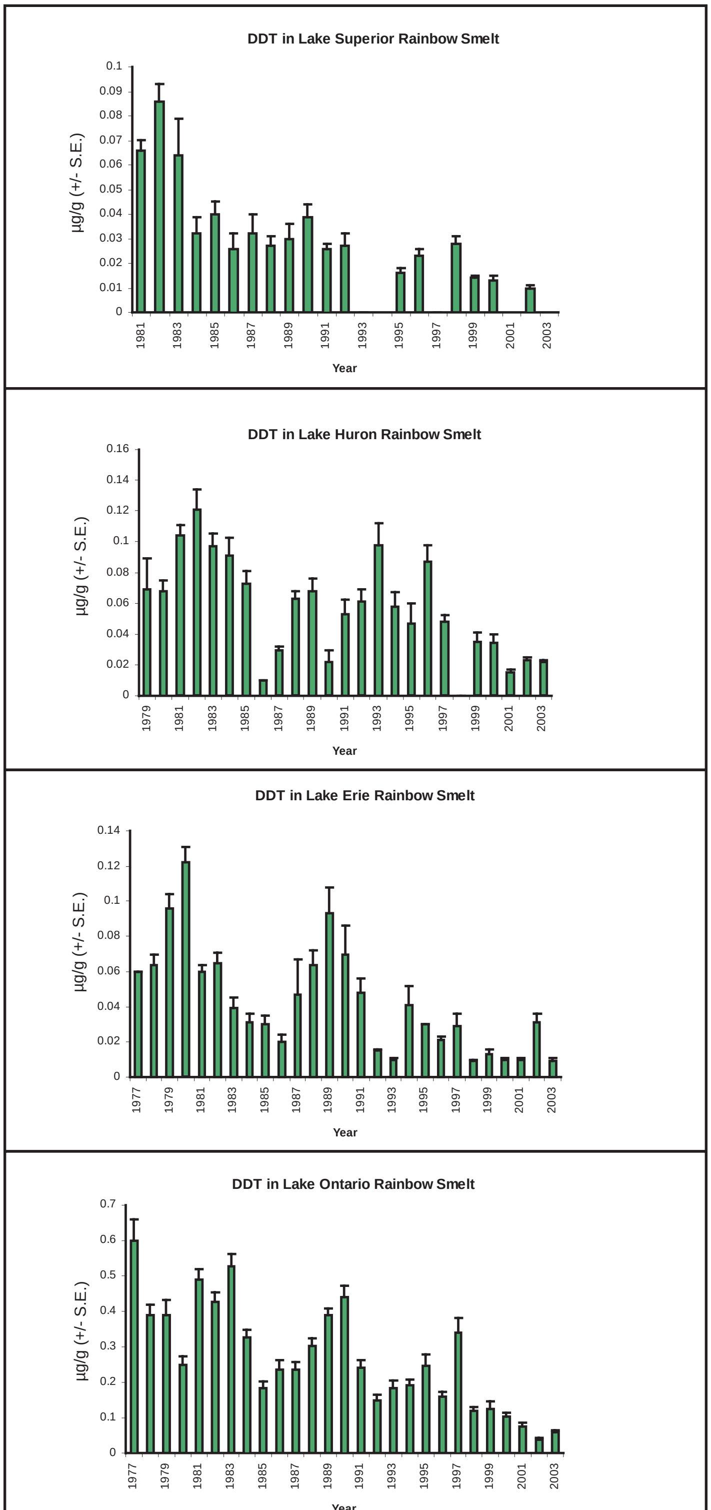

Figure 5. Total DDT levels in Great Lakes Rainbow Smelt, 1977-2003. Canadian data µg/g wet weight +/- S.E., whole fish. Note the different scales between lakes.
Source: Department of Fisheries and Oceans Canada

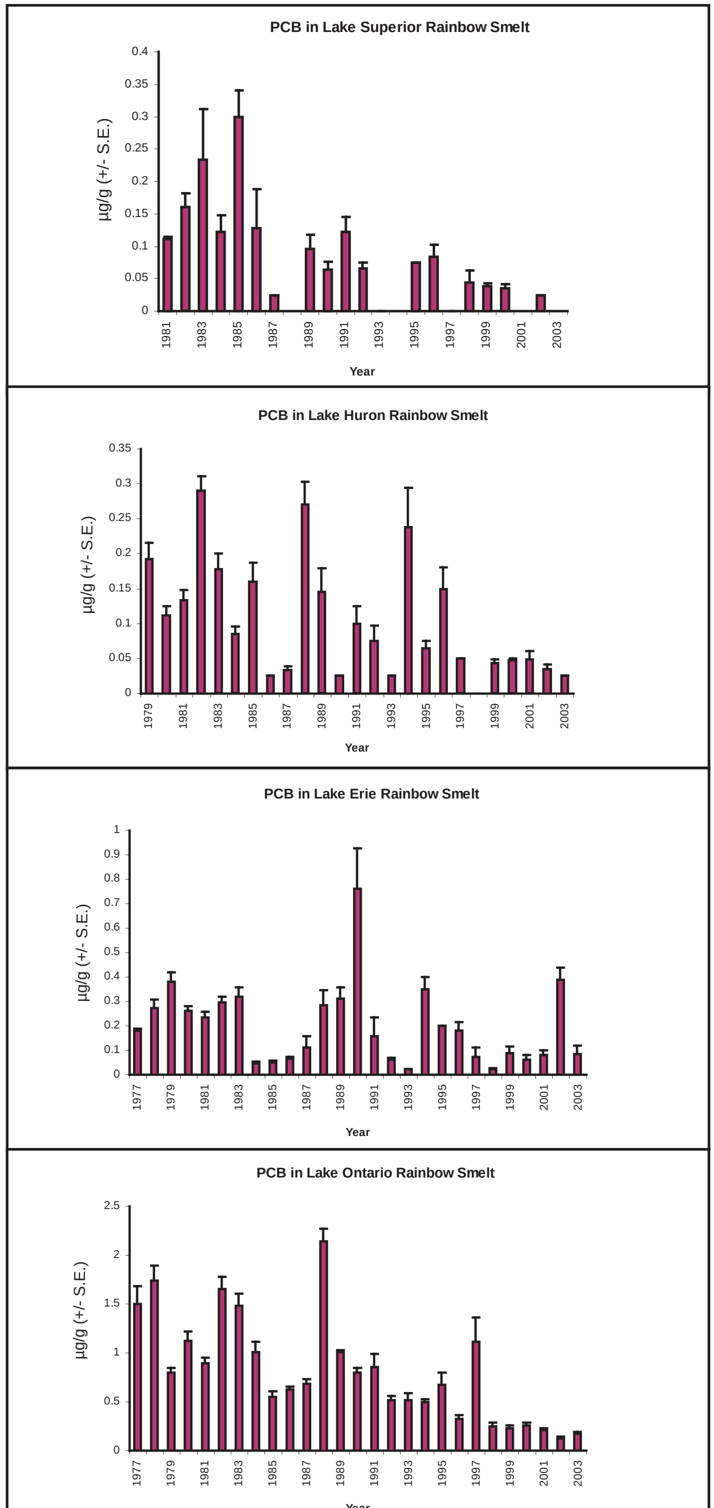

Figure 6. Total PCB levels in Great Lakes Rainbow Smelt, 1977-2003. Canadian data µg/g wet weight +/- S.E., whole fish. Note the different scales between lakes.
Source: Department of Fisheries and Oceans Canada

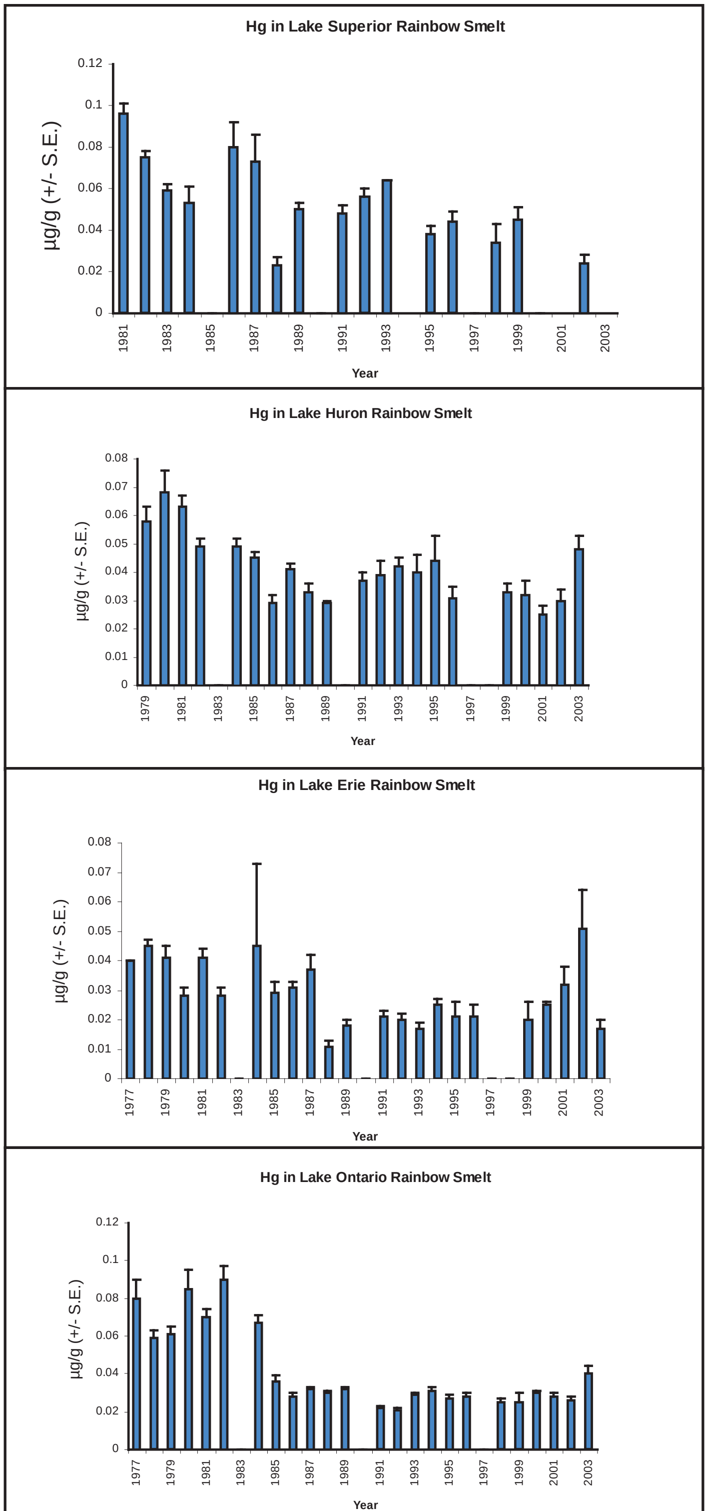

Figure 7. Total mercury levels in Great Lakes Rainbow Smelt, 1977-2003. Canadian data µg/g wet weight +/- S.E., whole fish. Note the different scales between lakes.
Source: Department of Fisheries and Oceans Canada

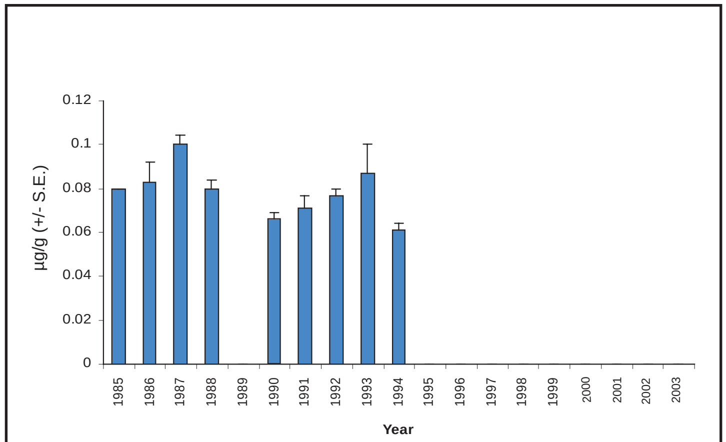

Figure 8. Total mercury levels in Lake Erie Lake Trout, 1985-1994. Canadian data µg/g wet weight +/- S.E., whole fish, ages 4-6 years.
Source: Department of Fisheries and Oceans Canada

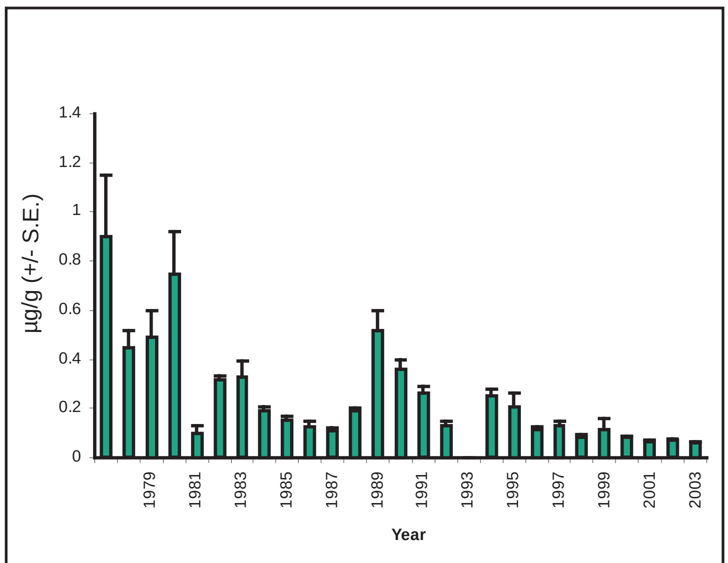

Figure 9. Total DDT levels in Lake Erie Walleye, 1977-2003. Canadian data µg/g wet weight +/- S.E., whole fish, ages 4-6 years.
Source: Department of Fisheries and Oceans Canada

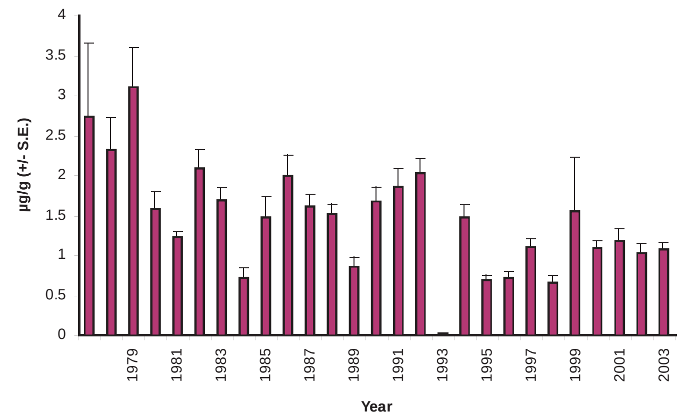

Figure 10. Total PCB levels in Lake Erie Walleye, 1977-2003. Canadian data µg/g wet weight +/- S.E., whole fish, ages 4-6 years.
Source: Department of Fisheries and Oceans Canada

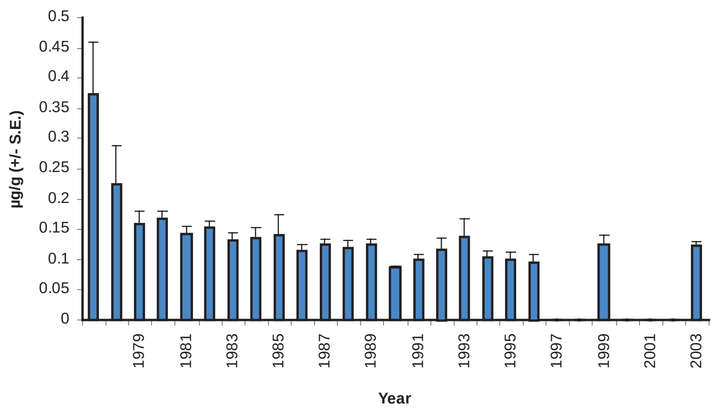

Figure 11. Total mercury levels in Lake Erie Walleye, 1977-2003. Canadian data µg/g wet weight +/- S.E., whole fish, ages 4-6 years.
Source: Department of Fisheries and Oceans Canada

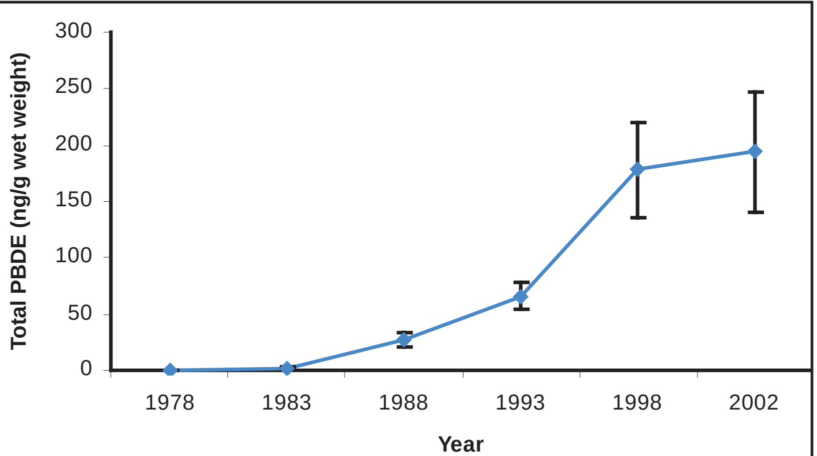

Figure 12. PBDE trends in Lake Ontario Lake Trout, 1978-2002. Canadian data ng/g wet weight +/- S.E.
Source: Department of Fisheries and Oceans Canada

Hexagenia

Indicator #122

Assessment: Mixed, Improving

Purpose

- To assess the distribution, abundance, biomass, and annual production of the burrowing mayfly (*Hexagenia*) in mesotrophic Great Lakes habitats.

Ecosystem Objective

Historically productive Great Lakes mesotrophic habitats, e.g., western Lake Erie; the Bay of Quinte, Lake Ontario; Saginaw Bay, Lake Huron; and southern and Green Bay, Lake Michigan, should be restored and maintained as balanced, stable, and productive elements of the Great Lakes ecosystem with *Hexagenia* as the dominant, large, benthic invertebrate.

State of the Ecosystem

Background

Hexagenia is used as an indicator of ecosystem health because it is intolerant of pollution and is thus a good reflection of water and lakebed sediment quality in mesotrophic Great Lakes habitats, where it was historically the dominant, large, benthic invertebrate and an important item in diets of many nearshore fishes. *Hexagenia* nymphs live for 1 or 2 years in surface sediments in the Great Lakes, emerging as sexually mature adults for a period of only hours to a day or so to mate and the females to deposit eggs before dying (Figure 1, Figure 2).

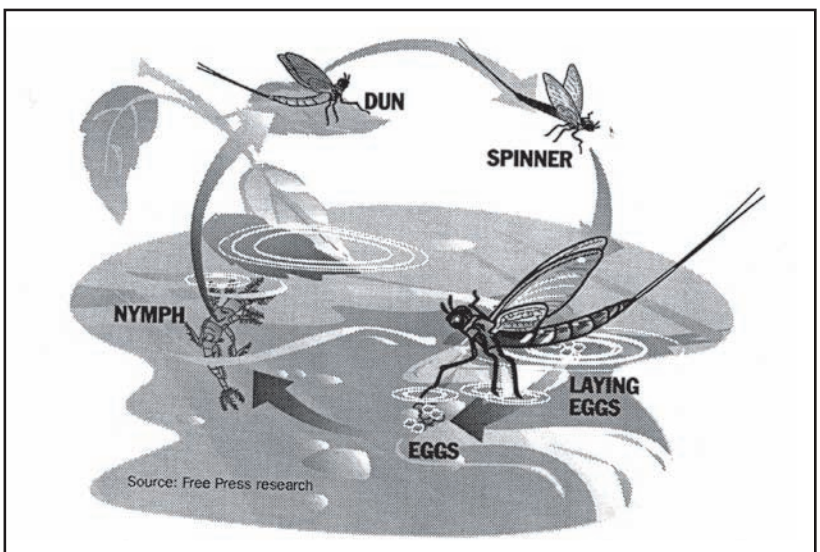

Figure 1. Hexagenia life cycle.
Source: Drawn by Martha Thierry, courtesy of the Detroit Free Press

Figure 2. Male Hexagenia.
Source: U.S. Geological Survey, Great Lakes Science Center

Status of *Hexagenia*

Major declines in the abundance of *Hexagenia* and low abundance or absence in some Great Lakes habitats where they were historically abundant have been linked to eutrophication and low dissolved oxygen in bottom waters and to pollution of sediments by metals and petroleum products. For example, *Hexagenia* was abundant in the western basin of Lake Erie in the 1930s and 1940s but an extensive mortality occurred in 1953. The population there recovered in 1954, but extirpation followed throughout the western basin by the early 1960s (reviewed in Schloesser *et al.* 2001). Improvements in water and sediment quality in historical *Hexagenia* habitat following the imposition of pollution controls in the 1970s were not immediately followed by the recovery of *Hexagenia* populations (Krieger *et al.* 1996). Surveys in spring 2001 indicated that; no recovery of *Hexagenia* occurred in Saginaw Bay, little recovery occurred in Green Bay, and a near-full recovery occurred in western Lake Erie (Edsall *et al.* 2002). In addition, Canadian biologists report the recovery of *Hexagenia* in the Bay of Quinte, Lake Ontario indicating pollution control programs have significantly improved the health of that habitat (personal communication Ron Dermott, Canadian Center for Inland Waters, Burlington, Ontario). However, *Hexagenia* was extirpated in polluted portions of the St. Marys and Detroit Rivers by the mid-1980s, and no recovery has yet been reported for some of these areas.

The recovery of *Hexagenia* in western Lake Erie is a sentinel event, which shows clearly that properly implemented pollution controls can bring about the recovery of a major Great Lakes mesotrophic ecosystem. With its partial recovery, the *Hexagenia* population in western Lake Erie will probably reclaim its functional status as a primary agent in sediment bioturbation and as a trophic integrator directly linking the detrital energy resource to fish, and particularly the economically valuable yellow perch-walleye community. The partial recovery of *Hexagenia* in western Lake Erie also helps remind us of one outstanding public outreach feature associated with using *Hexagenia* as an indicator of ecosystem health — the massive swarms of winged adults that are typical of healthy, productive *Hexagenia* populations in areas of historical abundance in the Great Lakes. These swarms are highly visible to the public who use them to judge the success of water pollution control programs and the health of Great Lakes mesotrophic ecosystems.

Pressures

The virtual extirpation and delayed recovery of the *Hexagenia* population in western Lake Erie was attributed to the widespread, periodic occurrence of anoxic bottom waters, although little evidence existed to support low oxygen persistence over the past 25 years. However, recent research has documented sporadic anoxia in portions of the western basin, and some data indicate different oxygen demand of sediments with and without recolonized mayfly nymphs (Bridgeman *et al.* In review; Schloesser *et al*. 2001; unpublished data, Schloesser). Most point-source inputs are now controlled, but in-place pollutants in lakebed sediments and non-point pollution appear to be a problem in some areas. Paved surface runoff, spills of pollutants, and combined sewer overflows also pose a major problem in some urban and industrial areas. Phosphorus loadings still exceed guideline levels in some portions of the Great Lakes and loadings may increase as the human population in the Great Lakes basin grows.

The effects of non-native species on *Hexagenia* and its usefulness as an indicator of ecosystem health are unknown and may be problematic. It has been postulated that the colonization of the western basin of Lake Erie by the zebra mussel (*Dreissena polymorpha*) and the recovery of *Hexagenia* are linked causally, but no specific mechanism has yet been proposed. Support for zebra mussel as a major factor in the recovery of *Hexagenia* in the western basin is perhaps eroded by the fact that Saginaw Bay, Lake Huron, is also heavily colonized by the zebra mussel, but the *Hexagenia* population there, which collapsed in 1955-1956, still has not shown signs of recovery.

Management Implications

Management activities that would foster the restoration and maintenance of *Hexagenia* populations in mesotrophics areas of the Great Lakes include:

- Regulation of point sources and non-point sources of pollution and sharply reduced spills of pollutants that enter nearshore waters to improve and maintain Great Lakes water and sediment quality consistent with the environmental requirements of healthy, productive populations of *Hexagenia*.

- Continuation of the development and application of technology and practices designed to restore lakebed and riverbed sediment quality in Areas of Concern (AOCs) and critical *Hexagenia* habitat areas that have problem levels of persistent, in-place pollutants.

- Development of a monitoring program to collect baseline data for *Hexagenia* populations in all major, historical, Great Lakes mesotrophic habitats so that changes in ecosystem health can be monitored and reported, management strategies evaluated and improved, and corrective actions taken to improve ecosystem health and to judge progress toward reaching interim and long term targets and goals.

- Implementation of monitoring protocols involving sampling in late spring, immediately prior to the annual emergence of adults.

- Research to describe the interactions between *Hexagenia* and introduced aquatic species and the effect of those species, if any, on the utility of *Hexagenia* as an indicator of ecosystem health.

- Determination of the most important limiting factor to recovery mayfly populations in nearshore waters of the Great Lakes.

- Development of predictive tools to estimate when mayfly populations will return to mesotrophic waters where they have not yet returned.

Acknowledgments

Author: Don W Schloesser, U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, MI, dschloesser@usgs.gov.

Sources

Bridgeman, T.B., Schloesser, D.W., Krause, A.E., and Goldman, S.L. In review. Recruitment of Hexagenia mayfly nymphs in western Lake Erie linked to environmental variability. *Ecological Applications*.

Edsall, T.A., Bur, M.T., Gorman, O.T., and Schaeffer, J.S. 2002. *Burrowing mayflies as indicators of ecosystem health: status of populations in western Lake Erie, Saginaw Bay (Lake Huron), and Green Bay (Lake Michigan).* Report to Great Lakes National Program Office, U.S. Environmental Protection Agency, Chicago, IL.

Edsall, T.A., Hass, R.C., and Adams, J.V. 2001. Production of burrowing mayfly nymphs in U.S. waters of Lake St. Clair. *J.*

Great Lakes Res. 27:449-456.

Krieger, K.A., Schloesser, D.W., Manny, B.A., Trisler, C.E., Heady, S.E., Ciborowski, J.J.H., and Muth, K.K. 1996. *J. Great Lakes Res*. 22:254-263.

Schloesser, D.W., Krieger, K.A., Ciborowski, J.J.H., and Corkum, L.D. 2001. Recolonization and possible recovery of burrowing mayflies in Lake Erie of the Laurentian Great Lakes. *J. of Aquatic Ecosystem Stress and Recovery* 8:125-141.

Abundances of the Benthic Amphipod *Diporeia* spp.

Indicator #123

Assessment: Mixed, Deteriorating
Diporeia populations are not declining in Lake Superior, but they are still doing so in Lakes Michigan, Huron, and Ontario.

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 is the most abundant benthic organism in cold, offshore regions (> 30 m) of each of the lakes. It is present, but less abundant in nearshore regions of the open lake basins, and is 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, and these species 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* is an important pathway by which energy is 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, are completely gone or very rare in Lake Erie, but appear stable in Lake Superior. In all the lakes except Superior, abundances have decreased in both nearshore and offshore areas over the past 12 years, and large areas are now nearly devoid of this organism. Based on most recent data, areas where *Diporeia* are known to be rare or absent include the southern/southeastern and northern portions of Lake Michigan at depths < 70 m, almost all of Lake Ontario at depths < 80 m, and the entire southern end and most nearshore areas (< 40 m) of Lake Huron (Figure 1). In Lake Erie, *Diporeia* are naturally absent from the shallower western and central basins, and are no longer present in the deeper eastern basin. In deeper areas of Lakes Michigan, Huron and Ontario, *Diporeia* are still present, but abundances are lower than abundances reported in the 1970s and 1980s.

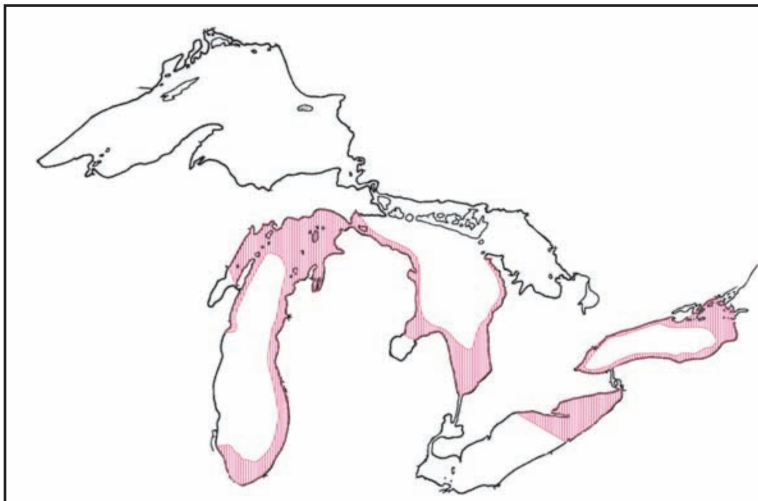

Figure 1. Areas in the Great Lakes where *Diporeia* were once present but have now completely disappeared (red hatch). *Diporeia* are naturally not present in inner Green Bay, inner Saginaw Bay, Lake St. Clair, and the western and central basins of Lake Erie. Because of insufficient data, areas of *Diporeia* loss in North Channel and Georgian Bay, Lake Huron are unknown. Populations are not declining in Lake Superior.
Source: National Oceanic & Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory

Typical decline patterns at three sites of different depths in Lake Ontario are given in Figure 2. Preliminary analysis of recent data (2003) collected in Lake Ontario indicates that *Diporeia* abundances remain generally similar to abundances found in 1998, with further declines noted along the north shore near Toronto. In all the lakes, population declines coincided with the introduction and rapid spread of the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena bugensis*). 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* has completely disappeared from areas where food is still settling to the bottom and where there are no local populations of mussels.

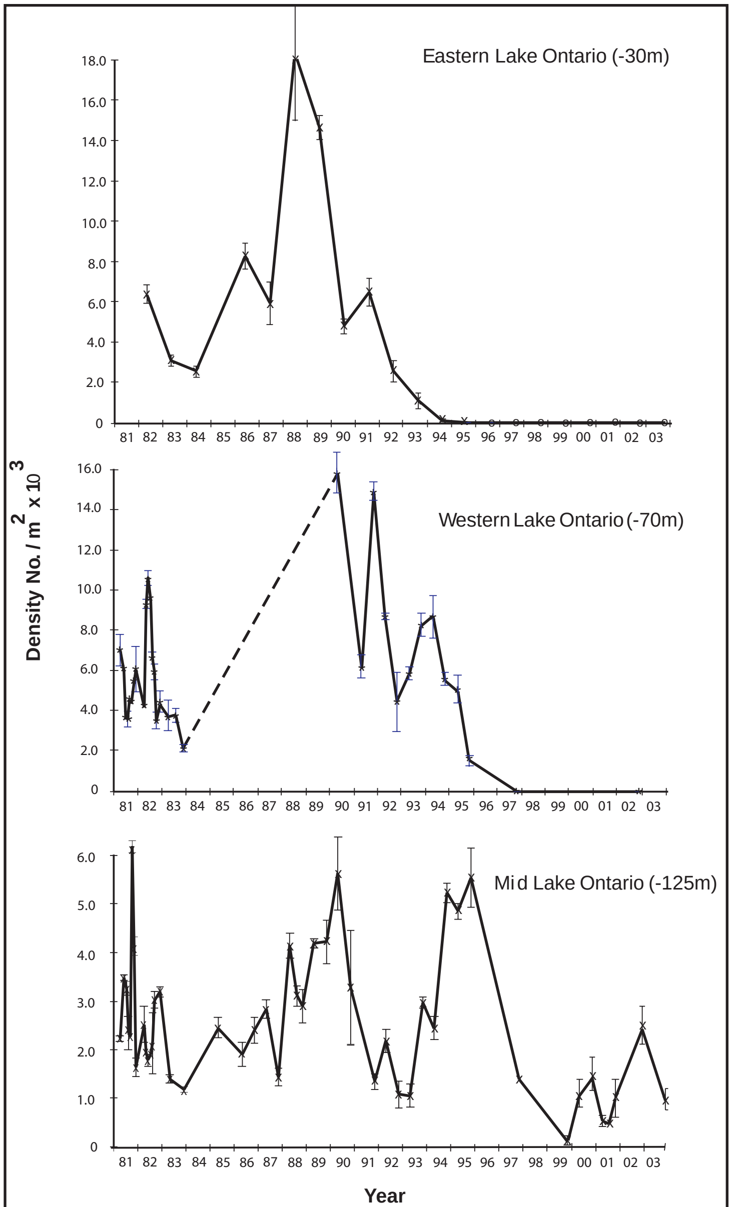

Figure 2. Trends in densities (no./m^2 x 10^3) of *Diporeia* at three sites in Lake Ontario between 1981 and 2003. The sites represent different depths and regions within the lake.
Source: Department of Fisheries and Oceans Canada

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 and Huron, zebra mussels are most abundant at depths less than 50 m, and *Diporeia* are now gone from lake areas as deep as 70 m. Quagga mussels have recently been reported from both lakes and, since quagga mussels tend to occur deeper than zebra mussels, the decline or complete loss of *Diporeia* will likely extend to depths > 70 m. In portions of Lake Ontario, *Diporeia* populations have disappeared at depths > 100 m.

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 fish 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, the abundance 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, the condition and abundance of other fish species such as alewife, slimy sculpin, and bloater have also 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.

Acknowledgments

Authors: T.F. Nalepa, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, MI.; and
R. Dermott, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, ON.

Sources

Dermott, R. 2001. Sudden disappearance of the amphipod *Diporeia* from eastern Lake Ontario, 1993-1995. *J. Great Lakes Res.* 27:423-433.

Dermott, R., and Kerec, D. 1997. Changes in the deepwater benthos of eastern Lake Erie since the invasion of *Dreissena*: 1979-1993. *Can. J. Fish. Aquat. Sci.* 54:922-930.

Hoyle, J.A., Shaner, T., Casselman, J.M., and Dermott, R. 1999. Changes in the lake whitefish (*Coregonus clupeaformis*) stocks in eastern Lake Ontario following *Dreissena* mussel invasion. *Great Lakes Res. Rev.* 4:5-10.

Lozano, S.J., Scharold, J.V., and Nalepa, T.F. 2001. Recent declines in benthic macroinvertebrate densities in Lake Ontario. *Can. J. Fish. Aquat. Sci.* 58:518-529.

Nalepa, T.F., Hartson, D.J., Fanslow, D.L., Lang, G.A., and Lozano, S.J. 1998. Declines in benthic macroinvertebrate populations in southern Lake Michigan, 1980-1993. *Can. J. Fish. Aquat. Sci*. 11:2402-2413.

Owens, R.W., and Dittman, D.E. 2003. Shifts in the diets of slimy sculpin (*Cottus cognatus*) and lake whitefish (*Coregonus clupeaformis*) in Lake Ontario following the collapse of the burrowing amphipod *Diporeia*. *Aquat. Ecosys. Health Manag.* 6:311-323.

Pothoven, S.A., Nalepa, T.F., Schneeberger, P.J., and Brandt, S.B. 2001. Changes in diet and body condition of lake whitefish in southern Lake Michigan associated with changes in benthos. *N. Amer. J. Fish. Manag.* 21:876-883.

Authors' Commentary

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. With an understanding of exactly why *Diporeia* populations are declining, we may better predict what additional areas of the lakes are at risk.

External Anomaly Prevalence Index (EAPI) for Nearshore Fish

Indicator #124

This indicator replaces indicator #101.

Assessment: Poor-Mixed, Undetermined

Purpose

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

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 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 (sometimes as 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. They must be carefully evaluated, however. 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.

Status of EAPI

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 (B) and/or lips (L) (Figure 1).

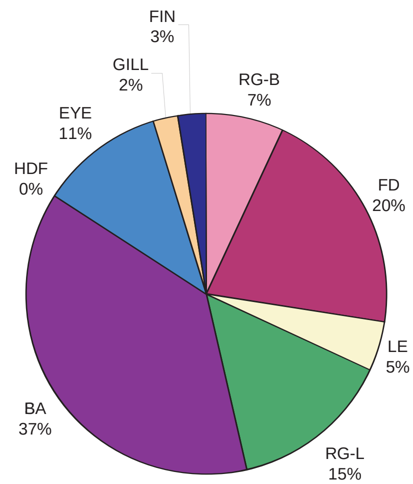

Figure 1. External anomalies on brown bullhead collected from Lake Erie from 1980s through 2000. BA - barbell abnormality, RG - raised growth (Body and Lip), FD - focal discoloration, LE - lesion, HDF - head and body deformities (total 2439 fish).
Source: Great Lake Science Center database, Ann Arbor, MI

Initial statistical analysis of sediments and external anomalies at different locations indicates that variations in the chemical mixtures (PAH, PCB, organochlorines (OC), metals) are reflected in a differing prevalence of individual external anomalies. Impairment determinations should be based on comparing the prevalence of external anomalies at potentially contaminated sites with the prevalence at "reference" (least impacted) sites. Preliminary data indicate that if the prevalence of raised growths on lips (lip papillomas) is > 10%, or the external raised growths on body and lip combined is >15% in brown bullhead, the population should be considered impaired. The additional use of barbell abnormalities and focal discoloration (melanistic alterations) helps to differentiate degrees of impairment of fish population health. A comparison of the three most common external anomalies on fish at Lake Erie AOCs to anomaly incidence at reference sites is presented in Figure 2.

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 metabo-

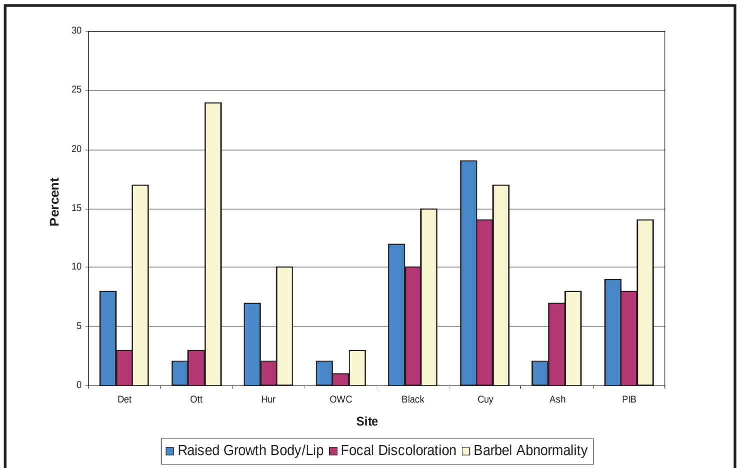

Figure 2. Prevalence of three most common external anomalies at Lake Erie AOCs. [Det - Detroit River, MI; OTT - Ottawa River, OH; Hur - Huron River, OH (Reference); OWC - Old Woman's Creek, OH (Reference); Black River, OH; Cuy - Cuyahoga River, OH - Cleveland Harbor and upstream combined; Ash - Ashtabula River, OH; PIB - Presque Isle Bay, PA].
Source: Smith *et al*. 2003

lites in bile and total PAH concentrations in sediment. The association with PAH metabolites in bile (Figure 3) is stronger than that with total PAH concentrations in sediments (Figure 4). 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 4) 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

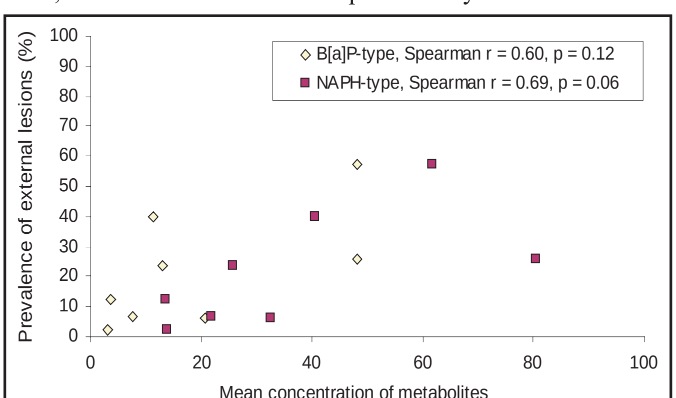

Figure 3. Prevalence of external raised lesions in brown bullhead from Lake Erie tributaries compared to PAH metabolite concentrations in bile (B[a]P and NAPH-type). Units are µg/mg protein.
Source: Yang and Baumann, unpublished data

statistically significant correlation between external raised lesions and concentrations of heavy metals in sediment (Figure 5).

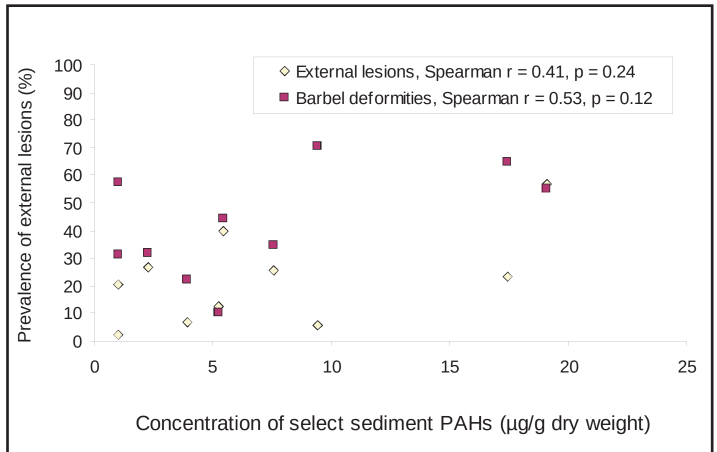

Figure 4. Prevalence of external raised lesions and barbel deformities in brown bullhead from Lake Erie tributaries compared to total PAH concentrations in sediment.
Source: Yang and Baumann, unpublished data

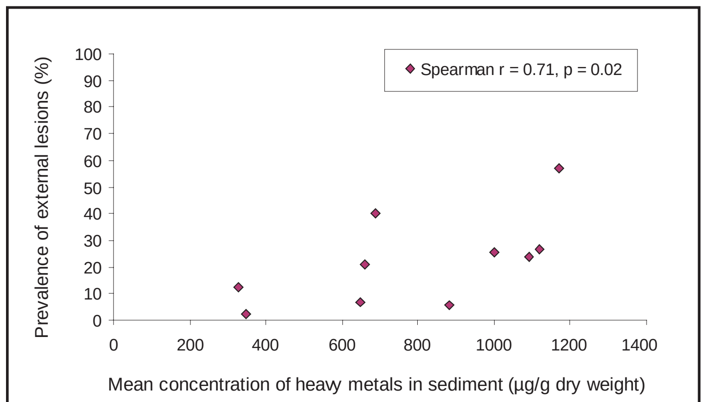

Figure 5. Prevalence of external raised lesions in brown bullhead from Lake Erie tributaries compared to concentrations of heavy metals in sediment.
Source: Yang and Baumann, unpublished data

Pressures

Some Great Lakes AOCs and their tributaries remain in a degraded condition. Exposure of the fish populations to contaminated sediments continues, and elevated incidence of external anomalies will persist. The human population in the Great Lakes basin is expected to increase, and urbanization along Great Lakes tributaries and shorelines will likely expand in the future. Thus, some locations impacted by land use changes may continue to deteriorate even as control and remediation actions improve conditions at the older contaminated sites.

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, 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).

Acknowledgments

Authors: Stephen B. Smith, U.S. Geological Survey, Biological Resources, Reston, VA;
Paul C. Baumann, U.S. Geological Survey, Biological Resources, Columbus, OH; and
Scott Brown, Environment Canada, National Water Research Institute, Burlington, ON.

Sources

International Joint Commission (IJC). 1996. *Indicators to evaluate progress under the Great Lakes Water Quality Agreement.* Indicators for Evaluation Task Force. ISBN 1-895058-85-3.

International Joint Commission (IJC). 1989. *Guidance on characterization of toxic substances problems in areas of concern in the Great Lakes Basin.* Report of the Great Lakes Water Quality Board, Windsor, ON.

Smith, S.B., Reader, D.R.P., Baumann, P.C., Nelson, S.R., Adams, J.A., Smith, K.A., Powers, M.M., Hudson, P.L., Rosolofson, A.J., Rowan, M., Peterson, D., Blazer, V.S., Hickey, J.T., and Karwowski, K. 2003. *Lake Erie Ecological Investigation; Summary of findings: Part 1; Sediments, Invertebrate communities, and Fish Communities: Part 2; Indicators, anomalies, Histopathology, and ecological risk assessment.* U.S.Geological Survey, Mimeo.

Authors' Commentary

This external anomaly indicator for benthic species has potential for defining habitats that are contaminated. Collaborative U.S. - Canadian studies investigating the etiology and prevalence of external anomalies in benthic fishes over a gradient of polluted to pristine Great Lakes habitats are needed. These studies would create a common index that could be used as an indicator of ecosystem health.

Status of Lake Sturgeon in the Great Lakes

Indicator #125

Assessment: Mixed, Undetermined

Purpose

- To assess the numbers of lake sturgeon in the Great Lakes and their connecting waterways and tributaries; and
- To infer a healthy or improving Great Lakes ecosystem when lake sturgeon are present in abundance.

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 management 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.

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).

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

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 underway by many groups to gather information on remnant spawning tributary and shoal populations in the Great Lakes. Lake sturgeon populations are known to be abundant in the connecting waterways of the Great Lakes. Very little information exists on juvenile lake sturgeon ages (0-2). 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).

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 (Zollweg *et al.* 2003). 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

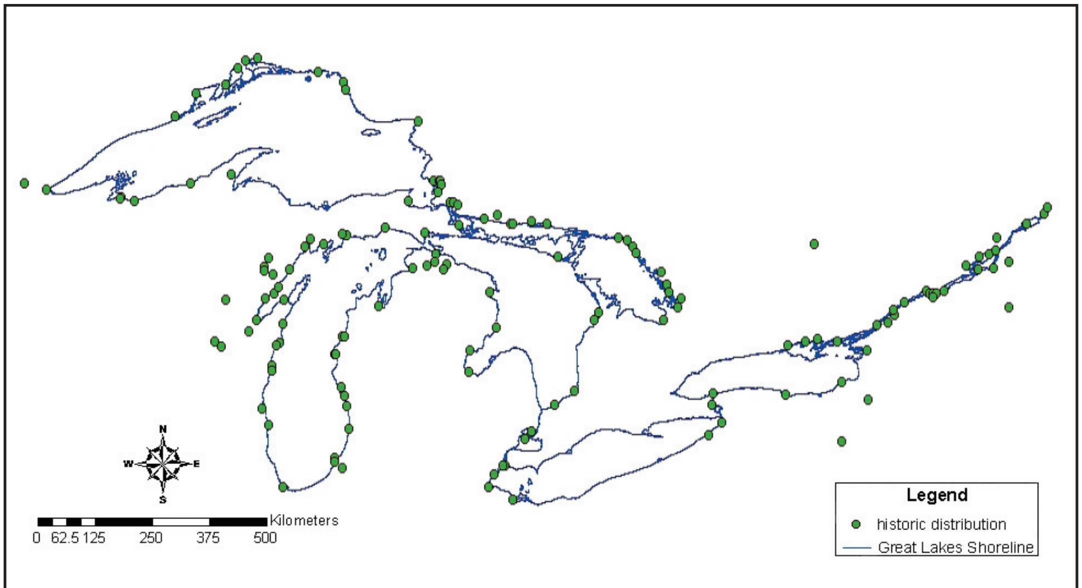

Figure 2. Historic distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

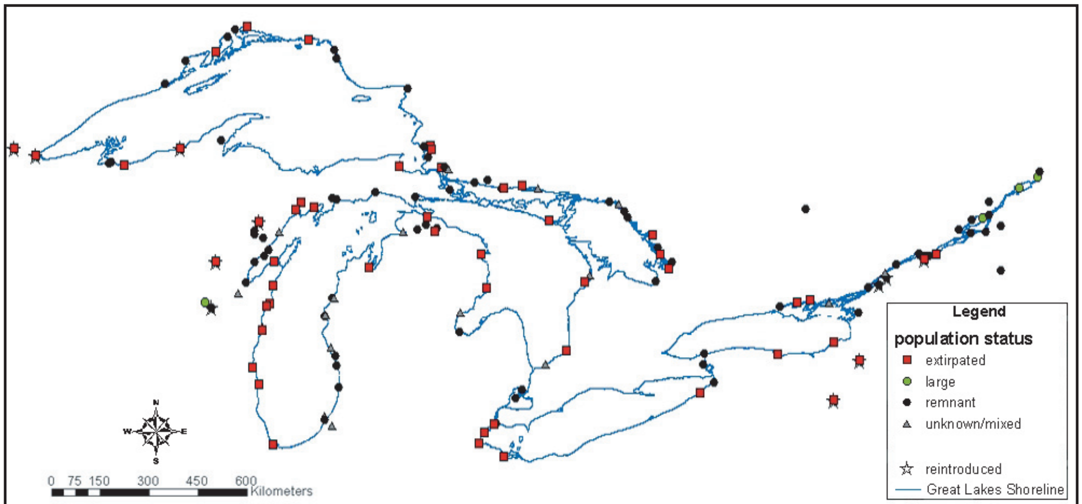

Figure 3. Current distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

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 Superior: The fish community of Lake Superior remains relatively intact in comparison to the other Great Lakes (Bronte *et al.* 2003). Considerable progress has been made rehabilitating indigenous populations of lake trout, lake whitefish, and lake sturgeon. 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 10 of these tributaries. Sturgeon populations in Lake Superior continue to sustain themselves at a small fraction of their historical abundance. Minimum rehabilitation targets and evaluation criteria have been established in the Rehabilitation Plan for Lake Superior (Auer 2003).

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. Most fishery agencies and several universities conduct dedicated sturgeon assessments or gather data from incidentally-caught lake sturgeon. 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. Tissue samples collected during these surveys will be used to describe the genetic structure and variation in Lake Superior sturgeon stocks, thereby providing information to evaluate population status and future management actions. 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.

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.

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 were stocked in Oneida Lake, Genesee River, Black Lake, St. Regis River and St. Lawrence River in 2003. 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.

Lake Erie: Lake Erie does not currently have lake sturgeon spawning activity documented in any major tributary except for the Detroit and St. Clair Rivers. Lake sturgeon tag recovery studies and telemetry research indicate that a robust lake sturgeon stock (> 45,000 fish) reside in the St. Clair River and Lake St. Clair (Thomas and Haas 2002). To date only three lake sturgeon spawning areas have been identified in the connecting waters between Lakes Huron and Erie (Manny and Kennedy 2002). Port Huron and Algonac are located on the St. Clair River and Zug Island located on the Detroit River. The western basin of Lake Erie continues to be a nursery area for juvenile lake sturgeon as indicated by periodic catches in commercial fishing nets. In the central and eastern basins of Lake Erie lake sturgeon are more scarce with only occasional catches of sub-adult or adult lake sturgeon in commercial fishing nets and none in research nets. Anchor Bay in Lake St. Clair may also be functioning as a nursery area as indicated by the capture of juveniles by researchers with Michigan Department of Natural Resources (MDNR). In 2004 research in the St. Clair River indicated that juveniles less than four years old could be consistently captured which may indicate that the large connecting waterways may also be important nursery areas, further research is scheduled for 2005 and 2006. 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 2006 to identify if spawning stocks of sturgeon are using smaller tributaries (Maumee River, Ohio) and shoal areas in western Lake Erie.

Lake Huron: 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 6,500 sturgeon tagged in Saginaw Bay, southern Lake Huron, Georgian Bay and the North Channel. Tag recoveries 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 is being assessed to determine if lake sturgeon are using that system for spawning. The project is ongoing and will continue through 2007. Similar research is being planned for the Thunder and Rifle Rivers in Michigan and the St. Marys River system in the near future. Research efforts will continue to focus on identifying tributaries supporting spawning stocks of lake sturgeon, genetic difference between stocks, habitat requirements, migration patterns, testing archival tag technology and contaminant testing methodologies.

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).

Acknowledgments

Authors: Emily C. Zollweg, U.S. Fish and Wildlife Service, Lower Great Lakes Fishery Resources Office, 405 N. French Rd., Suite 120A, Amherst, NY 14228.
Emily_Zollweg@fws.gov;
Robert F. Elliott, U.S. Fish and Wildlife Service, Green Bay Fishery Resources Office, 2661 Scott Tower Drive, New Franken, WI 54229;
Henry Quinlan, U.S. Fish and Wildlife Service, Ashland Fishery Resources Office, 2800 Lakeshore Drive E., Ashland, WI 54806;
John Weisser, U.S. Fish and Wildlife Service, Marquette Biological Station, 1924 Industrial Parkway, Marquette, MI 49855; and
James Boase, U.S. Fish and Wildlife Service, Alpena Fishery Resources Office, 145 Water Street, Alpena, MI, 49707.
James_boase@fws.gov.

Sources

Auer, N.A. (ed.). 2003. *A lake sturgeon rehabilitation plan for Lake Superior*. Great Lakes Fishery Commission Misc. Publ. 2003-02.

Baldwin, N.S., Saalfeld, R.W., Ross, M.A., and Buettner, H.J. 1979. *Commercial fish production in the Great Lakes 1867-1977*. Great Lakes Fishery Commission Technical Report 3.

Bronte, C.R., Ebener, M.P., Schreiner, D.R., DeVault, D.S., Petzold, M.M., Jensen, D.A., Richards, C., and Lozano, S.J. 2003. Fish community changes in Lake Superior, 1970-2000. *Can. J. Fish. Aquat. Sci*. 60: 1552-1574.

Eckert, T.H. 2004. Summary of 1976-2003 Warm Water Assessment. In *New York State Department of Environmental Conservation. Lake Ontario Annual Report 2003*. Bureau of Fisheries, Lake Ontario Unit and St. Lawrence River Unit. Cape Vincent and Watertown, NY.

Harkness, W.J., and Dymond, J.R. 1961. *The lake sturgeon: The history of its fishery and problems of conservation.* Ontario Dept. of Lands and Forests, Fish and Wildl. Branch. 120 pp.

Hay-Chmielewski, E.M., and Whelan, G.E. 1997. *Lake sturgeon rehabilitation strategy.* Michigan Department of Natural Resources Fisheries Division, Special Report Number 18, Ann Arbor, MI.

Hill T.D., and McClain, J.R. (eds.). 2004. *2002 Activities of the Central Great Lakes Binational Lake Sturgeon Group*. U.S. Fish and Wildlife Service, Alpena, MI.

Holey, M.E., Baker, E.A., Thuemler, T.F., and Elliott, R.F. 2000. *Research and assessment needs to restore Lake Sturgeon in the Great Lakes*: *results of a workshop sponsored by the Great Lakes Fishery Trust*. Lansing, MI.

Manny, B.A., and Kennedy, G.W. 2002. Known lake sturgeon (*Acipenser fulvescens*) spawning habitat in the channel between Lakes Huron and Erie in the Laurentian Great Lakes. *J. Applied Ichthyology* 18:486-490.

Ontario Ministry of Natural Resources. 2004. *Lake Ontario Fish Communities and Fisheries: 2003 Annual Report of the Lake Ontario Management Unit*. Ontario Ministry of Natural Resources, Picton, ON.

Thomas, M.V., and Haas, R.C. 2002. Abundance, age structure, and spatial distribution of lake sturgeon, *Acipenser fulvescens*, in the St. Clair system. *J. Applied Ichthyology* 18: 495-501.

Zollweg, E.C., Elliott, R.F., Hill, T.D., Quinlan, H.R., Trometer, E., and Weisser, J.W. (eds.). 2003. Great Lakes Lake Sturgeon Coordination Meeting. In *Proceedings of the December 11-12, 2002 Workshop*, Sault Ste. Marie, MI.

Authors' Commentary

More information is needed to determine ways to get lake sturgeon past barriers on rivers. More monitoring is needed to determine the current status of Great Lakes lake sturgeon populations. More information is also needed on juvenile lake sturgeon. More law enforcement is needed to protect large adult lake sturgeon. 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.

Commercial/Industrial Eco-Efficiency Measures

Indicator #3514

This indicator report is from 2003.

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.

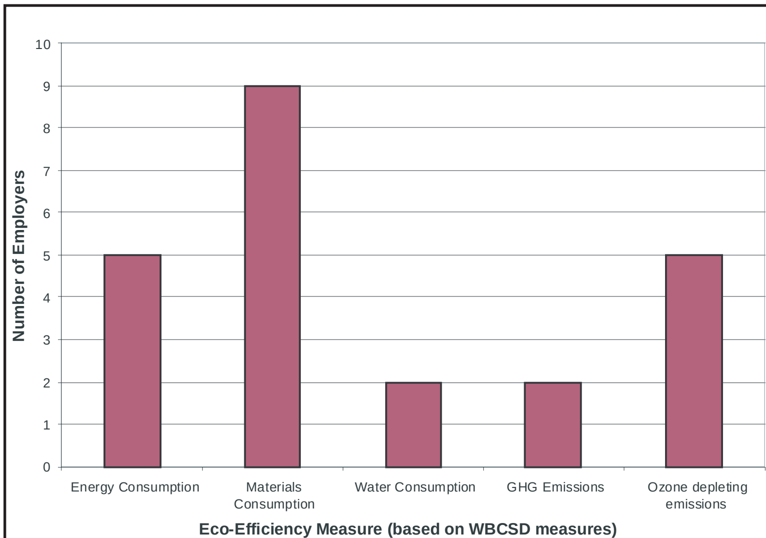

Figure 1. Number of the 24 largest employers in the Great Lakes basin that publicly report eco-efficiency measures. GHG = green house gas. Source: WBCSD = World Business Council for Sustainable Development

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.

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.

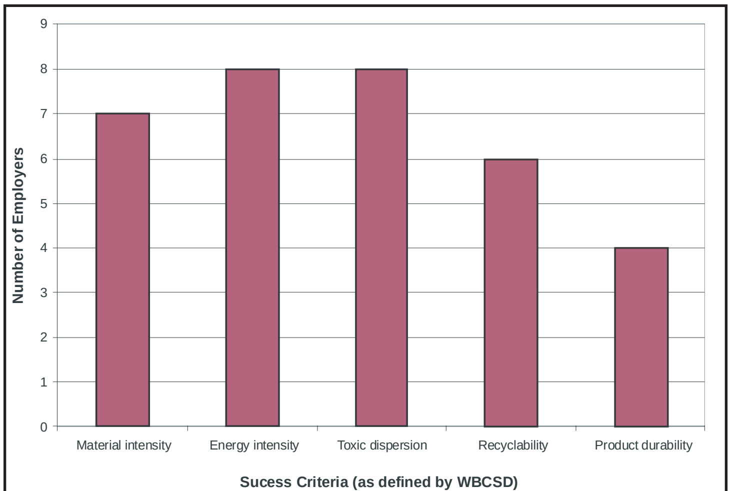

Figure 2. Number of the 24 largest employers in the Great Lakes basin that publicly report initiatives related to eco-efficiency success criteria.
Source: WBCSD = World Business Council for Sustainable Development

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.

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.

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Author: Laurie Payne, LURA Consulting, Oakville, ON.
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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.

Sources

InfoUSA®, Omaha, NE. Largest Employers Database. 2001 www.acinet.org, employers.database@infoUSA.com.

Organization for Economic Cooperation and Development (OECD), Environment Policy Committee, Environment Directorate. 1998. Eco-Efficiency: Environment Ministerial Steering Group Report. Paris, France.

Report on Business Magazine. 2002. *The TOP 1000 2002: 50 Largest Employers*. http://top1000.robmagazine.com, last accessed July 1, 2002.

Stratos: Strategies to Sustainability in collaboration with Alan Willis and Associates and SustainAbility. 2001. *Stepping Forward: Corporate Sustainability Reporting in Canada*.

Vrooman Environmental Inc. and Legwork Environmental Inc. for Industry Canada. 2001. *The Status of Eco-Efficiency and Indicator Development in Canadian Industry*. A Report on Industry Perceptions and Practices.

World Business Council on Sustainable Development (WBCSD). 2000. *Eco-efficiency: creating more value with less impact*.

World Business Council on Sustainable Development (WBCSD). 2000. *Measuring eco-efficiency: A guide to reporting* *company performance*.

World Business Council on Sustainable Development (WBCSD). 1996. *Eco-efficient Leadership for Improved Economic and Environmental Performance*. Geneva, Switzerland.

National Round Table on Environment and Economy, Ottawa. 1999. *Measuring eco-efficiency in business: feasibility of a core set of indicators*.

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.

Drinking Water Quality

Indicator #4175

Assessment: Good, Unchanging

Purpose

- To evaluate the chemical and microbial contaminant levels in source water and in treated drinking 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 reservation. As such, the treated water should be free from harmful chemical and microbiological contaminants. This indicator supports Great Lakes Water Quality Agreement Annexes 1, 2, 12, and 16.

State of the Ecosystem

Background

Information provided by the United States focuses mainly on finished, or treated, drinking water due to the difficulty of obtaining raw water data. In addition, finished (or treated) water was chosen as the focus for U.S. reporting in order to adapt to the recommendations of the Environmental Health Indicator Project, http://www.cdc.gov/nceh/indicators/default.htm. Information provided by Canada focuses on both finished, or treated, and raw, or source, water. It is important to note that raw water can always 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.

Due to the difficulty of gathering and analyzing raw water data in the U.S., finished water has been chosen as the best way to display drinking water quality in U.S. Water Treatment Plants (WTPs). Canadian information has been provided for both raw and finished water. Information gathered for this report was collected from 57 U.S. Water Treatment Plants and 74 Canadian Drinking Water Systems (DWSs).

In the U.S., the Safe-Drinking Water Act Re-authorization of 1996 requires all drinking water utilities to provide water quality information to their consumers every year. To satisfy this requirement, U.S. WTPs provide an annual Consumer Confidence/Water Quality Report (CC/WQR) to their customers. The CC/WQRs include information on source water type (i.e. lake, river, groundwater or other source), the water treatment process, contaminants detected in finished water, any violations, and other relevant information. For this indicator report the CC/WQRs were collected for the operational year 2002 (2003 when available) for WTPs catering to population centres in the Great Lakes basin equal to or greater than 50,000 people. Additional WTPs, catering to less than 50,000 people, were added to provide better geographic coverage (Figure 1).

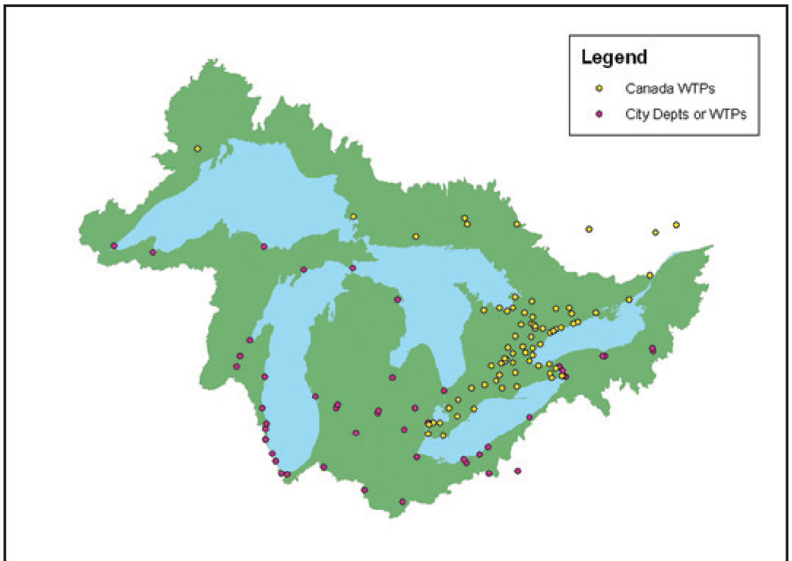

Figure 1. Analysis for drinking water indicator report is based upon 57 Water Treatment Plants (U.S.) and 74 Drinking Water Systems (Canada).
Source: U.S. Environmental Protection Agency and Environment Canada

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 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, were also provided for analysis.

There are several Great Lakes basin sources of drinking water including lakes, rivers, streams, ponds, reservoirs, springs, and wells. Water travelling over the surface of the land or through the ground is vulnerable to contamination by naturally occurring minerals, substances resulting from animals or anthropogenic activity, and in some instances, radioactive material. 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. Finished and raw water evaluated for this report originated from many water sources in the Great Lakes basin including the Great Lakes themselves, rivers, small lakes/reservoirs, and groundwater. 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.

Status of Drinking Water in the Great Lakes Basin

Ten drinking water parameters were chosen to provide the best assessments of drinking water quality in the Great Lakes basin, including several chemical parameters, microbiological parameters, and other indicators of potential health hazards. It is important to note that the majority of these parameters are no longer present in the finished water stage of the drinking water treatment process.

Chemical Contaminants

Chemical contaminants of concern include atrazine, nitrate, and nitrite. These parameters can be present in raw and finished water. Exposure to these contaminants above the regulated standards has the potential to negatively affect human health.

Atrazine - Atrazine can enter source waters through its use as an herbicide and/or through effluents from manufacturing facilities. Consuming drinking water containing atrazine in excess of the standard can potentially lead to health complications depending on the length of exposure. The U.S. Environmental Protection Agency (USEPA) set the Maximum Contaminant Level (MCL) for atrazine at 3 parts per billion (ppb) and the Ontario drinking water standards specify the Interim Maximum Acceptable Concentration (IMAC) to be 5 ppb. The Interim Maximum Acceptable Concentration is established for parameters either when there are 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. These levels were established as the lowest level to which the WTPs/ DWSs could reasonably be required to remove this contaminant if it were present in drinking water given the present technology and resources.

In the U.S., atrazine rarely occurred in finished waters supplies. It was found only in finished water originating from Lake Erie, rivers, groundwater, and small lake/reservoirs. When detected, it was present at levels below the MCL. Violations of monitoring requirements were reported for one WTP that uses water from small reservoirs for failure to monitor for atrazine and other pesticides during February through most of June of 2003. However, no violations of the MCL were reported. The risk for human exposure to atrazine is low as indicated by the annual CC/WQRs.

In the 2004 Ontario data, atrazine was detected in both raw and treated water; however, the detections in treated water were never in amounts that exceeded the IMAC. In the Ontario DWSP 2001/2002 data, the highest atrazine result detected for 134 raw and 325 treated water samples were .55 ppb and 0.58 ppb respectively, which is about one order of magnitude smaller than the IMAC for atrazine (5 ppb). Therefore, the 2001/2002 DWSP data do not show any atrazine concentration above the Ontario IMAC. The 3 highest water sample results in 2001/2002 DWSP data were found in treated water samples where the raw water source is located in an agricultural watershed.

Nitrogen - Nitrogen is a nutrient that occurs naturally in the environment and is used in many agricultural applications. However, nitrogenous materials tend to be converted to nitrate in natural waters. Ingestion of drinking water containing nitrate exceeding the MCL or Maximum Acceptable Concentration (MAC) can cause serious health effects, particularly to infants. The USEPA has set the MCL for nitrate at 10 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 finished water supplies from WTPs using all source water types and repeatedly detected in water originating from Lake Erie, Lake Ontario, Lake Superior, and small lakes/reservoirs. While it was seen as a reoccurring contaminant, it was never detected above the MCL. Therefore, while there is some risk of exposure to nitrate, it is not likely to lead to serious health complications.

The Ontario data indicated that there were no observed results for nitrate in treated drinking water samples at levels above the standard at any of the reporting drinking water systems.

In the U.S., nitrite was rarely detected in finished water supplies. It was found in water using Lake Erie, Lake Michigan, river, groundwater, and small lakes/reservoirs source water. As such, there is a small potential for human exposure to nitrite from drinking water. No nitrite violations were reported.

The Ontario data indicated that there were no observed results for nitrite in treated drinking water samples at levels above the standard at any of the reporting drinking water systems. In the DWSP 2001/2002 data the highest result values for 574 raw and 442 treated water samples were 0.434 ppm and 0.017 ppm, respectively.

Microbiological Parameters
Microbiological parameters evaluated include total coliform, *Escherischia coli (E .coli), Giardia,* and *Cryptosporidium.* These microbial contaminants are included as indicators of water quality and as an indication of the presence of hazardous and possibly fatal pathogens to humans. They occur predominately in raw water, however inadequate treatment techniques or contamination post-treatment may result in their presence in finished 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 coliforms in tap water that states that large WTPs that are required to take more than 40 samples/ month must not find total coliforms in more than 5% of their monthly samples. Smaller WTPs required to take less than 40 samples/month must not find total coliforms in more than two of their monthly samples. 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 discern if specific types of coliform, such as fecal coliforms or *E. coli*, are present.

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 Huron, groundwater, and small lakes/reservoirs as source water. Violations of monitoring requirements of USEPA's Total Coliform Rule (TCR) were reported in one WTP, for not collecting any or not collecting enough monthly routine samples for total coliform bacteria analysis during eight months of 2002. TCR repeat monitoring reporting violations were also reported for three other WTPs, for not collecting any or not collecting enough repeat samples after coliform bacteria was detected in monthly routine samples. Repeat samples must be collected at the same location 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. There were a total of four repeat monitoring violations at these U.S. WTPs in the basin, two in 2002 and two in 2003. While coliform bacteria were detected in the majority of finished water supplies, they were not found exceeding the MCL. Although there is potential for human exposure to total coliform, it is not likely to present a human health hazard in itself. However, the presence of coliform bacteria indicates the possibility that microbial pathogens may be present, and this can be hazardous to human health.

In Ontario, total coliform were detected in many of the raw water samples. The presence of total coliform was detected in treated water only on three occasions. It can be concluded that the treatment facilities are adequately removing the total coliform.

Escherichia coli (*E. coli*) - *E. coli* is a type of thermo tolerant (fecal) coliform bacteria that is generally found in the intestines of all animals, including humans. *E. coli* bacteria derived from animal and human fecal waste commonly enters source water through contaminated runoff water as a result of precipitation, among other routes of exposure. Detection of *E. coli* in water strongly indicates recent contamination of sewage or animal waste, which may contain many types of disease-causing organisms. *E. coli* bacteria may persist in drinking water after inadequate treatment. Both the U.S. and Canada require WTPs/DWSs to monitor for coliform bacteria. If monitoring tests reveal the presence of coliform bacteria, the same positive samples must be further analyzed for either fecal coliform or *E. coli*. 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., *E. coli* was detected in a limited number of routine samples from one WTP using source water from a small lake. Despite this occurrence, there were no violations associated with this finding because, presumably, all of the total coliform repeat samples taken in response to the *E. coli* positive routine samples were negative. It was not detected in any of the other finished water supplies.

In Ontario, *E. coli* was detected in small amounts in raw water samples taken from Lake Erie, Lake Ontario, Lake Superior and Lake St. Clair. It was also detected in small amounts in other small lakes and rivers. The Detroit River and the Grand River had few occurrences of higher readings. Although *E. coli* was detected in raw water, its presence was not detected in any treated drinking water samples. Thus, it can be concluded that the treatment facilities and processes are working adequately, however the sources of the *E. coli* in the raw water data should be investigated to determine the state of the environment.

Giardia and *Cryptosporidium* - *Giardia* and *Cryptosporidium* are parasites that exist in water and when ingested may cause gastrointestinal illness in humans. The presence of these microorganisms in treated water is controlled by treated water standards. The U.S. standards 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. This limit is confirmed by limits on 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* was detected in finished water supplies from any of the WTPs, as indicated by the CC/WQRs. However, their presence in raw water was discussed in the majority of the CC/WQRs and are reported as raw water information in 2002. The presence of these organisms in source water and 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 the potential for consumers to be exposed to the aforementioned microbiological contaminants. However, it is not likely that exposure to the contaminants from drinking water will lead to any serious health complications. Total coliform was the most common microbiological contaminant detected in finished water, however there were no confirmed detections of the more serious contaminants including *E. coli, Giardia,* and *Cryptosporidium* in finished water in the U.S. and no confirmed detections of *E. coli* in treated water in Ontario.

Treatment Technique Parameters
Treatment technique parameters evaluated include turbidity and total organic carbon (TOC) in the U.S. and dissolved organic carbon (DOC) in Canada. These parameters do not pose a direct health hazard but are often indicative of other health hazards.

Turbidity - If turbidity levels in raw water are very high, they can inhibit the effectiveness of the disinfection/filtration process, conceal potentially hazardous microorganisms, and can be comprised of toxic particulate matter or that which is capable of absorbing or bonding with toxic substances. A significant relationship has been demonstrated between turbidity increases and the number of *Giardia* cysts and *Cryptosporidium* oocysts breaking through filters. In finished water, turbidity can also act as an indicator of the efficiency of the drinking water treatment process. In the U.S., with some possible exceptions, all systems using a surface water source or a groundwater source under the direct influence of surface water must install filtration and disinfection treatment and meet filtration technique requirements. These requirements depend on the type of filtration treatment and the population served. For systems using conventional or direct filtration treatment serving 10,000 or more people, turbidity levels of filtered water must be less than or equal to 0.3 Nephelometric Turbidity Unit (NTU) in at least 95% of the measurements taken each month, and at no time can they exceed 1 NTU. Ontario has set the aesthetic objective for turbidity at 5.0 NTU, at which point turbidity becomes visible to the naked eye.

U.S. turbidity data were difficult to assess due to the varying formats of CC/WQRs and the way the data were presented. As such, it was difficult to assess quantitatively and compare the turbidity levels reported for finished water by each WTP. In 2002, four treatment technique violations were reported, however it appears the violations were not related to turbidity levels as they were well within the designated standards. Violations of reporting requirements were reported for two WTPs for failure to report monthly filter turbidity monitoring results for two months in 2003 at one WTP, and one month in 2003 at the other WTP.

The aesthetic objective for turbidity in the Ontario Drinking Water Quality Standard (ODWQS) is 5.0 NTU at the point of consumption, and in DWSP 2001/2002 data, out of 385 samples, there was one treated water sample result of 7.74 NTU that exceeded the aesthetic objective. In the 2004 Ontario data, there were three instances reported where turbidity was detected, none of which surpassed 5.0 NTU. All three detections were in treated water, two from a groundwater source, and one from a canal.

Total Organic Carbon - Although the presence of TOC in water does not directly imply a health hazard, the organic carbon reacts with chemical disinfectants to form harmful byproducts. TOC is removed from water by WTPs using conventional treatment 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 alkalinity level of the raw water. A TOC and alkalinity analysis for these WTPs can be used to determine how much TOC the system can reasonably remove from the raw water. The USEPA does not have a MCL for TOC.

TOC was detected in finished water from WTPs using all source water types, except those using Lake Huron and Lake Superior source water. It was repeatedly detected in finished water from WTPs using Lake Erie source water. Violations of monitoring requirements were reported for two conventional WTPs for failure to collect monthly TOC and alkalinity levels in raw water and combined filter effluent during all twelve months of 2002.

Dissolved Organic Carbon - Dissolved organic carbon (DOC) can indicate the possibility of water deterioration during storage and distribution due to the fact that carbon can be a growth nutrient for biofilm-dwelling bacteria. Biofilm is a term for the microbial cells that attach to pipe surfaces and multiply to form a film or slime layer on the pipe which can harbor and protect coliform bacteria from disinfectants. High DOC levels also indi cate the potential of chlorination by-product 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.

The 2001/2002 data for Ontario had one DOC violation out of 442 samples in treated water. The violation in the treated water sample had a value of 9.3mg/L and was from a small lake. There were only two occurrences of DOC reported in Ontario for January through June 2004. Both occurrences were in treated drinking water, but did not exceed the aesthetic objective. The largest concentration of the two was 4.5 ppm from a small lake.

Taste and Odour

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

In the U.S., several complaints of bad taste and odour were recorded during the summer months. These were attributed to natural compounds released by benthic algae, which cause a distinct taste and odour during the warmer months. There were also complaints of chlorine taste and odour from customers of WTPs using Lake Michigan source water.

Summary

The quality of finished drinking water in the Great Lakes basin is good based on the information provided by the annual CC/WQRs and the Ontario annual reports from the DWSs. These reports can be utilized to evaluate the efficiency of current treatment technologies. The information provided demonstrates that WTPs/DWSs are employing treatment technologies that are successfully treating water, thus enabling them to provide quality drinking water. Few, if any, violations of federally, provincially or state regulated MCLs, MACs, or treatment techniques occurred. Other violations are also infrequent, supporting the claim that drinking water quality is good. The risk of human exposure to the noted chemical and/or microbiological contaminants is generally low. Therefore, the potential for humans to develop serious health complications as a result of consuming drinking water containing these contaminants from the Great Lakes basin is also low.

Pressures

Previous Great Lakes drinking water indicator reports evaluated drinking water contaminants in raw water based upon their potential human health hazard. Although the majority of these contaminants are removed during the treatment process and therefore do not pose a human health hazard, the analysis and reporting of contaminants in raw water is still useful. In the event of a WTP failure, a storm water event, or a cut in funding, it is possible that raw water would not be treated properly before entering distribution systems. Therefore, it is important to maintain the quality of raw water. Contaminants in raw water are indicative of the potential human exposure, and the degree to which water must be treated to remove the contaminants. It is further indicative of the level of pollutant input to the region's potable water supply.

The greatest pressures come from degraded runoff. Reduced quality of runoff may be caused by a number of factors, including the increasing rate of industrial development on or near water bodies, low-density urban sprawl, and agriculture, including both crop and livestock operations. In addition, point source pollution, such as that from wastewater treatment plants, also can contribute to contamination of raw water. It is unknown to what extent new pressures such as newly introduced chemicals, chemicals of emerging concern or invasive species will impact water quality. If these problems persist, microbiological and chemical contaminants, in addition to disinfection byproducts, could pose a health risk.

Management Implications

A more standardized approach to reporting the status of drinking water in the Great Lakes basin needs to be created in the United States. Issues such as evaluation of raw vs. finished water, the size of WTPs/DWSs included in analysis, and standardized reporting formats need to be decided upon in order to best assess the potential human health hazard from drinking water. It is difficult to establish trend analysis of drinking water based upon CC/WQRs, as each report is issued in a different format and includes different information. A database containing all relevant information, accessible to all WTPs/DWSs, researchers, and the public, would aid in this process.

While the evaluation of finished water is important in order to protect human health, it is also vital to maintain the quality of raw water. Even a well-operated WTP cannot ensure that drinking water will be completely free of *Cryptosporidium*. For example, the detection of *Cryptosporidium* in finished water may be underestimated as analytical methods for *Cryptosporidium* have accuracy and reliability limitations.

The scattered geographical coverage provided by focusing on WTPs serving a population of 50,000 or greater in the U.S. provides a fragmented view of the drinking water patterns in the Great Lakes basin. However, sporadically including additional WTPs to expand geographic coverage may introduce bias. In Ontario, the data for all DWSs serving a population of 10,000 or greater was analyzed. Future efforts should adhere to clear guidelines when identifying usable data, such that the information provided offers adequate geographical coverage and sufficient data.

While there are many precautions exercised to ensure quality finished water, contamination is also possible during the distribution stage and even as it travels through personal plumbing systems. For example, many WTPs/DWSs are engaging in actions to prevent corrosion of copper or lead from home and business plumbing pipes into water supplies and to limit bacterial growth. Continued sampling in the distribution stage, in combination with effective treatment to prevent future contamination at the finished water stage will continue to ensure quality drinking water at the consumer tap.

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Authors: Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL; Christyanne Melendez, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL; and Lindsay Silk, Environment Canada, Downsview, ON.

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Sources

Guillarte, A., and Makdisi, M. 2003. *Implementing Indicators 2003, A Technical Report*. Environment Canada and U.S. Environmental Protection Agency. http://binational.net/sogl2003/sogl03_tech_eng.pdf, last accessed March 11, 2005.

Jarvis, L. 2004. Personal Communication. *Ontario Reg 170/03 Drinking Water Data (Jan-Jun 2004), Drinking Water Program Management Branch, Drinking Water Management Division*, Ontario Ministry of the Environment.

Ontario Ministry of the Environment. 2003. *Technical Support Document for Ontario Drinking Water: standards, objectives and guidelines.* Ontario Ministry of the Environment.

Sharifi, M. 2004. Personal Communication. *Ontario 2001/2002 Drinking Water Surveillance Program (DWSP) Data, Environmental Monitoring and Reporting Branch, Environmental Sciences and Standards Division*, Ontario Ministry of the Environment.

Consumer Confidence Reports

Akron Public Utilities Bureau Akron Metropolitan Service Area – Annual Drinking Water Quality Report for 2002
Alpena Water Treatment Plant – 2002 Annual Water Quality Report
Alpena Water Treatment Plant – 2003 Annual Water Quality Report
Ashland Water Utility – 2003 Consumer Confidence Report
Buffalo Water Authority – Annual Drinking Water Quality Report for 2003
City of Ann Arbor Water Utilities – 2002 Annual Report on Drinking Water
City of Ann Arbor Water Utilities – 2003 Annual Report on Drinking Water
City of Battle Creek Public Works – Water and Wastewater – 2002 Water Quality Report
City of Cleveland – 2002 Cleveland Water Quality Report
City of Duluth Public Works and Utilities Department – Duluth Water During 2002
City of Evanston – 2002 Water Quality Report
City of Evanston – 2003 Water Quality Report
City of Kenosha – 2002 Annual Drinking Water Report
City of Manistique – 2002 Water-Quality Report
City of Manistique – 2003 Water-Quality Report
City of Muskegon Water Filtration Plant (WFP) – 2002 Annual Water Quality Report
City of Muskegon Water Filtration Plant (WFP) – 2003 Annual Water Quality Report
City of Rochester – 2002 Water Quality Report
City of Sheboygan Water Utility – Sheboygan Water Utility Annual Report, Summer 2003
City of St. Ignace – 2002 Water Quality Report
City of Syracuse, Department of Water – Annual Drinking Water Quality Report for 2003
City of Toledo – Drinking Water Quality Report for 2002
City of Waukegan - Waukegan Water Quality Report – 2002
City of Wyoming – 2002 Water Quality Report
Consumers Ohio Water-Company (COWC) – 2002 Water Quality Report (lake shore Division)
Consumers Ohio Water-Company (COWC) – 2002 Water Quality Report (Stark Regional Division)
Consumers Ohio Water-Company (COWC) – 2002 Water Quality Report (Suburban Division)
Department of Utilities Appleton Water Treatment Facility – 2002 Annual Water Quality Report
Detroit Water and Sewerage Department – Water Quality Report 2002
East Lansing-Meridian Water and Sewer Authority – Consumer Confidence Report for 2002
Elyria Water Department – 2002 Annual Water Quality Report
Erie County Water Authority – 2002 Water Quality Report
Erie Water Works (EWW) – Water Quality Report for Year 2002
Fort Wayne City Utilities – 2003 Annual Drinking Water Quality Report
Grand Rapids Water System – 2002 Water Quality Report
Green Bay Water Utility – 2003 Annual Drinking Water Quality Report

Hammond Water Works Department – 2002 Annual Drinking Water Quality Report
Indiana-American Water Company, Inc. (Northwest Operations) – 2002 Annual Water Quality Report
Indiana-American Water Company, Inc. (Northwest Operations) – 2003 Annual Water Quality Report
Lake County Department of Utilities Division of Water – Water Quality Report 2002
Lansing Board of Water & Light – 2002 Annual Water Quality Report
Lima Water Treatment Plant – 2002 Drinking Water Consumer Confidence Report
Lorain Water Purification Plant – Annual Water Quality Report for 2002
Lorain Water Purification Plant – Annual Water Quality Report for 2003
Michael C. O'Laughlin Municipal Water Plant – Annual Drinking Water Quality Report for 002
Milwaukee Water Works – 2002 Water Quality Report
Milwaukee Water Works – 2003 Water Quality Report
Monroe County Water Authority – 2002 Annual Water Quality Report
Onondaga County Water Authority (OCWA) – 2002 Consumer Confidence Report & Annual Water Supply Statement
Oshkosh Water Utility – 2002 Consumer Confidence Report
Oshkosh Water Utility – 2003 Consumer Confidence Report
Port Huron Water Treatment Plant – 2002 Annual Drinking Water Quality Report
Racine Water Utility – Annual Water System Report for 2002
Saginaw Water Treatment Plant – Annual Drinking Water Quality Report for 2002
South Bend Water Works – Water Quality Report 2002
The City of Chicago – Water Quality Report 2002
Town of Tonawanda Water System – Annual Drinking Water Quality Report for 2003
Waterford Township – 2003 Water Quality Report

Authors' Commentary

Quality drinking water is an invaluable resource, one that should not be taken for granted. It is apparent from the annual CC/WQRs that the U.S. states in the Great Lakes basin have been active in conducting source water assessments. Ontario is also developing source water protection measures. In many cases, assessment results were used to develop or initiate development of source water protection measures. WTP/DWS intake and other source water monitoring data are needed to help determine if source waters are meeting applicable water quality standards for drinking water and attaining their designated use as sources of drinking water as well as the need for and measuring the success of source water protection efforts.

Our scientific detection limits lag behind the true presence of pathogens and chemicals in our environment. As such, one must take a conservative approach in conclusions regarding risk and safety. Additional research is needed on chemicals and pathogens of emerging concern.

Biological Markers of Human Exposure to Persistent Chemicals

Indicator #4177

This indicator has had a title change since 2003.

Assessment: Mixed, Undetermined

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).

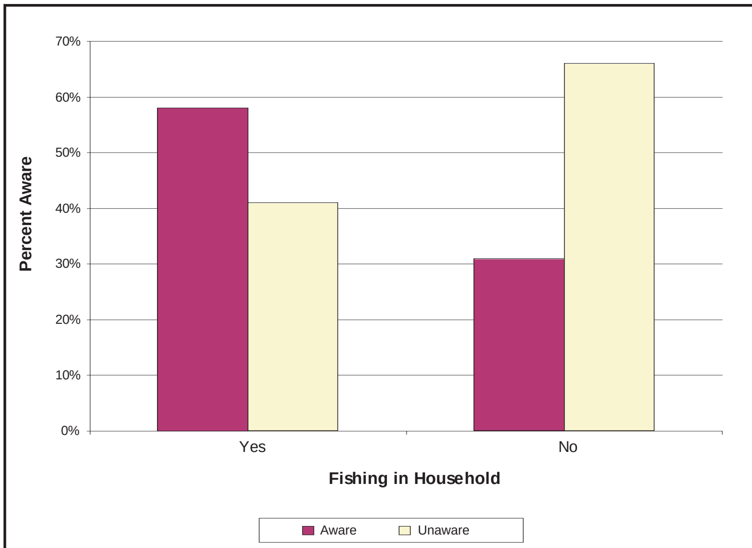

Figure 1. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories and who do (yes) or do not (no) have someone in the household who fishes.
Source: Wisconsin Department of Health and Family Services

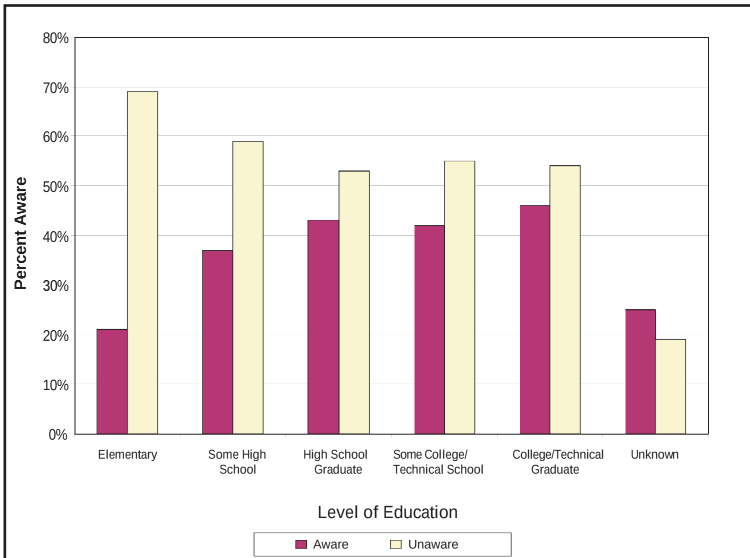

Figure 2. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to level of education.
Source: Wisconsin Department of Health and Family Services

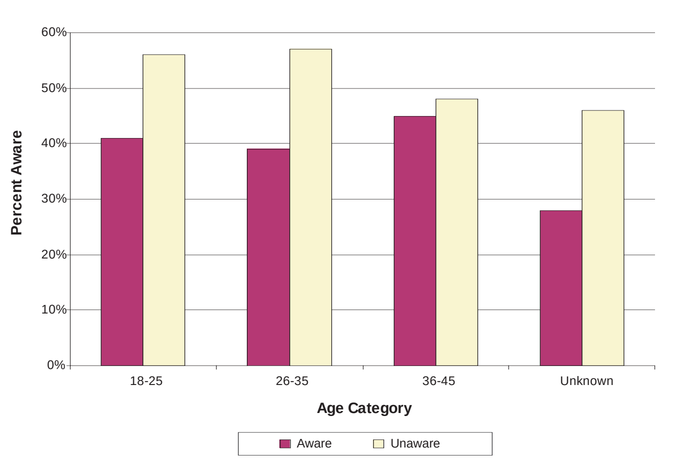

Figure 3. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to age group.
Source: Wisconsin Department of Health and Family Services

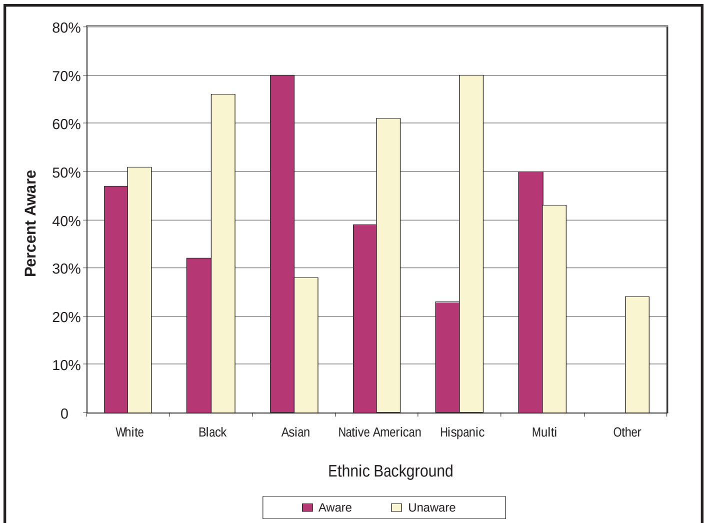

Figure 4. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to race.
Source: Wisconsin Department of Health and Family Services

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).

Person ID	Fish Consumption History	PCB (µg/l)	DDE (µg/l)	Mercury (µg/l)
1	Commercial = 1/week Sport Caught = none	0.0	0.34	< 5
2	Commercial = 5/month Sport Caught = 30/year	0.0	0.40	< 5
3	Commercial = < 6/year Sport Caught = 6 - 12/year	0.0	0.25	< 5
4	Commercial = 1/week Sport Caught = 1/week	0.4	1.20	< 5
5	Commercial = 4/month Sport Caught = 2/month	0.0	0.49	< 5

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

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 sur-

No. of fish meals / 3 months Sport Caught (Y/N)	Min (µg/g)	Average (µg/g)	Max (µg/g)	Number of Respondents	Average no. of fish meals
0	0.00	0.07	0.24	14	0
1 - 9 (N)	0.04	0.16	0.59	28	2.30
1 - 9 (Y)	0.03	0.30	0.99	7	2.40
10+ (N)	0.04	0.33	1.23	7	12.80
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

vey 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.

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Authors: Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office;
Jacqueline Fisher, U.S. Environmental Protection Agency, Great Lakes National Program Office;
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Sources

Anderson, H. 2004. *SOLEC Health Indicator Refinement and Implementation Progress Report.* Wisconsin Department of Health and Family Services. March, 22, 2004.

Bloom M.S., Vena, J.E., Swanson, M.K., Moysich, K.B., and Olsen, J.R. 2005. Profiles of ortho-polychlorinated biphenyl congeners, dichlorodiphenyl dichloroethylene, hexachlorobenzene, and mirex among male Lake Ontario sport fish consumers: the New York state angler cohort study. *Environ. Res.* 97(2):177-193.

Buck, G.M., Grace, P.T., Fitzgerald, E.F., Vena, J.E., Weiner, J.M., Swanson, M., and Msall, M.E. 2003. Maternal fish consumption and infant birth size and gestation: New York state angler cohort study. *Environ. Health* 2:7-15.

Davies, K., and Phil, D. 2001. *EAGLE Project: Contaminants in human tissue.* Health Canada, Ottawa, ON.

Fitzgerald, E.F., Hwang, S.A., Lambert, G., Gomez, M., and Tarbell, A. 2005. PCB exposure and in vivo CYP1A2 activity among Native Americans. *Environ. Health Perspect*. 113(3):1-6.

Mendola, P., Robinson, L.K., Buck, G.M., Druschel, C.M., Fitzgerald, E.F., Sever, L.E., and Vena, J.E. 2005. Birth defects associated with maternal sport fish consumption: potential effect modification by sex of offspring. *Environ. Res*. 97:133-140.

Ryan, J.J. 2004. *Polybrominated Diphenyl Ethers (PBDEs) in Human Milk; Occurrence Worldwide.* Prepared for the 2004 BFR (Brominated Flame Retardants) conference. Health Products and Food Branch, Health Canada, Toronto, ON.

Stewart P.W., Fitzgerald, S., Rehiman, J., Gump, B., Lonky, E., Darvill, T.J., Pagano, J., and Hauser, P. 2003a. Prenatal PCB exposure, the corpus callosum, and response inhibition. *Environ. Health Perspective* 111:1670-1677.

Stewart, P.W., Reihman, J., Lonky, E.I., Daravill, T.J., and

Pagano, J. 2003b. Cognitive development in preschool children parentally exposed to PCBs and MeHg. *Neurotoxicol. Teratol.* 25:11-22.

Tee, P.G., Sweeney, A.M., Symanski, E., Gardiner, J.C., Gasior, D.M., and Schantz, S. 2003. A longitudinal examination of factors related to changes in serum polychlorinated biphenyl levels. *Environ. Health. Perspect.* 111(5):720-707.

Weisskopf, M.G., Anderson, H.A., Hanrahan, L.P., Kanarek, M.S., Falk, C.M., Steenport, D.M., Draheim, L.A., and the Great Lakes Consortium. 2005. Maternal exposure to Great Lakes sport-caught fish and dichlorodiphenyl dichloroethylene, but not polychlorinated biphenyls is associated with reduced birth weight. *Environ. Res*. 97:149-162.

Authors' Commentary

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.

Beach Advisories, Postings and Closures

Indicator #4200

Note: This indicator replaces E. coli and Fecal Coliform Levels in Nearshore Recreational Waters (#4081).

Assessment: Mixed, Undetermined

Note: Data are not system-wide and multiple data sources are not consistent.

Purpose

- To assess the number of health-related swimming advisory, beach closure and / or 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, and/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 advisory, closure day or 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*, or 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 a maximum count of 100 *E. coli* 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.

The bacteria criteria recommendations for *E. coli* from the U.S. Environmental Protection Agency (USEPA) are a single sample maximum value of 235 colony forming units per 100 ml (or 235/100 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 closed, advisories are issued, or postings are displayed to inform swimmers.

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 closings, postings and advisories at beaches.

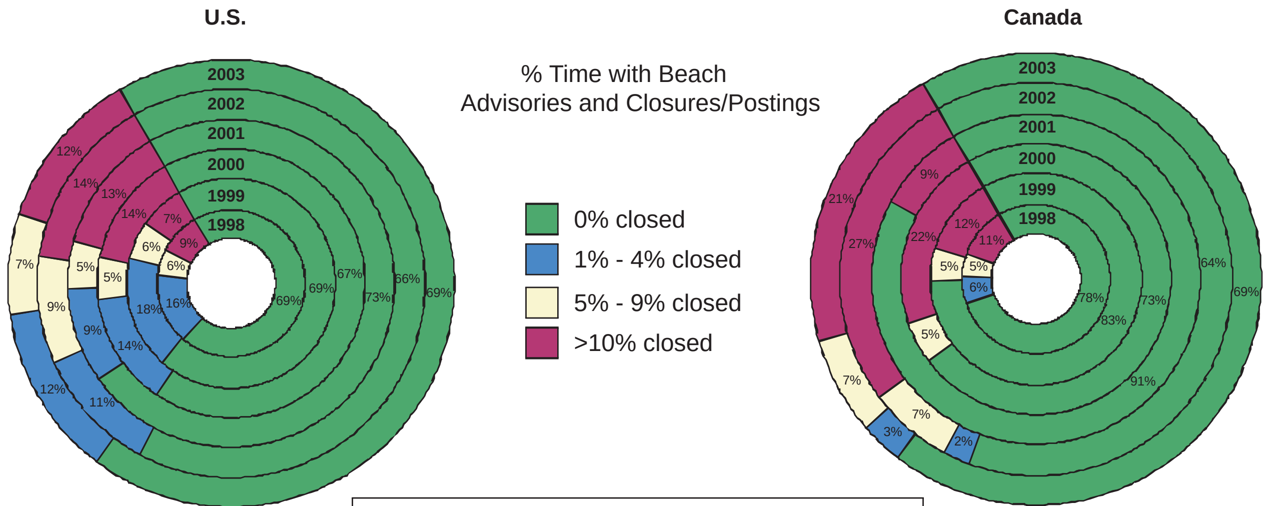
Status of Great Lakes Beach Advisories, Postings and Closures

Figure 1 shows that as the frequency of monitoring and reporting increases in the U.S. and Canada, more advisories, postings and closures are also observed, especially after 1999. In fact, both countries experienced an approximate percentage doubling of beaches that had advisories, closings or 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 2003 has expanded significantly (more than double since 2001) due to funding from the BEACH Act of 2000, however, the percentage of U.S. beaches open all season and the percentage of beaches closed more than 10% of the season in 2003 are virtually unchanged when compared to 2000-2002. While the number of beaches reporting in 2002 and 2003 in Canada decreased, there was a large increase in the number of beaches that posted advisories due to *E. coli*.

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 in the near future through current



Number of Great Lakes Beaches Reported Each Year		
Year	U.S.	Canada
2003	649	270
2002	383	272
2001	309	304
2000	329	293
1999	316	238
1998	298	218

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

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 closings, advisories, or postings are typically limited due to the use of different water quality criteria in different localities. In the U.S., all coastal states have criteria as protective as USEPA's recommended bacteria criteria (use of *E. coli* or enterococci indicators) applied to their coastal waters beginning in 2005. 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 closings/postings and / or advisories, 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 or beach closures exists in addition to the lifting of any restrictions from the beach when safe levels are again reached. The inability to develop a rapid test protocol for *E. coli* is lending support to advanced models to predict when to post beach closures.

Management Implications

In the U.S., the BEACH Act is funded through 2005. 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 modelling capability.

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Authors: Harold Leadlay, Environment Canada, Ontario Region, Downsview, ON;
Susan Arndt, Environment Canada, Ontario Region, Burlington, ON;
David Rockwell, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL;

Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL; and
Holiday Wirick, U.S. Environmental Protection Agency, Region 5 - Water Division, Chicago, IL.

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Sources

Canadian data obtained from Ontario Health Units along the Great Lakes.

Health Canada. 1999. *Guidelines for Canadian Recreational Water Quality, 1992*. http://www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/recreational_water.htm, last accessed July 12, 2002.

Ministry of Health, Algoma Health Unit. 1998. *Beach management protocol - safe water program.* http://www.ahu.on.ca/health_info/enviro_health/enviro_water/enviro_water_BeachManagement%20Protocol.htm, last accessed July 12, 2002.

Mitchell, D. 2002. *E. coli* testing may have outlived usefulness. *The Times Online*. http://www.thetimesonline.com/index.pl/articlesubpc?id=23927743, last accessed July 17, 2002.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987.* Ottawa and Washington. http://www.on.ec.gc.ca/glwqa/.

U.S. Environmental Protection Agency (USEPA). 2002a. *Great Lakes strategy 2002*. http://www.epa.gov/glnpo/gls/index.html, last accessed March 14, 2005.

U.S. Environmental Protection Agency (USEPA). 2002b. *National beach guidance and required performance criteria for grants*. www.epa.gov/OST/beaches, last accessed March 14, 2005.

U.S. Environmental Protection Agency (USEPA). 2002c. *National health protection survey of beaches for swimming (1998 to 2001*). http://www.epa.gov/waterscience/beaches, last accessed March 14, 2005.

U.S. Environmental Protection Agency (USEPA). 1986. *Ambient water quality criteria for bacteria - 1986.* www.epa.gov/OST/beaches, last accessed March 14, 2005.

Authors' Commentary

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/wfmmp/index.htm.

The Great Lakes Strategy 2002 (http://www.epa.gov/glnpo/gls/index.html) 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. 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.

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 modelling 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 closed/posted or have advisories issued. 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 may be addressed in the near future. The BEACH Act requires USEPA to study issues associated with pathogens and human health and to publish new or revised Clean Water Act Section 304(a) criteria. 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.

Contaminants in Sport Fish

Indicator # 4201

Assessment: Mixed, Improving

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 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.

Consumption advice groups Sensitive* and general populations	Concentration of PCBs (ppm)
Unrestricted consumption	0 - 0.05
1 meal/week	0.06 - 0.2
1 meal/month	0.21 - 1.0
6 meals/year	1.1 - 1.9
Do not eat	> 1.9

* Women of childbearing age and children under 15

Table 1. Uniform Great Lakes Sport Fish Consumption Advisory.
Source: Great Lakes Sport Fish Advisory Task Force, 1993

Advice for the 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 polychlorinated biphenyls (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.

Advised meals per month		Concentration of PCBs (ppm)
Sensitive populations*	General populations	
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 2. Guide to Eating Ontario Sport Fish.
Source: Ontario Ministry of the Environment

State of the Ecosystem

Program History

Both the United States and Canada 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 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 (Minnesota Department of Natural Resources salmon fillet data for Lake Superior) 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 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.

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, PBT chemicals, because of their ability to bioaccumulate and persist in the environment, 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.

Lake	Contaminants that Fish Advisories are based on in Canada and the United States
Superior	PCBs, mercury, dioxin, toxaphene, chlordane
Huron	PCBs, mercury, dioxin, toxaphene, chlordane
Michigan	PCBs, mercury, dioxin, chlordane
Erie	PCBs, mercury, dioxin
Ontario	PCBs, mercury, dioxin, toxaphene, mirex

Table 3. 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

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 contaminant levels, Ontario average-size (60cm) lake trout were chosen as the representative species due to their presence in all of the Great Lakes and their potential for exploitation by anglers. 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 Great Lakes Sport Fish Consumption Advisory, by year. Other important differences between the GLNPO and OMOE programs include composite analysis vs. individual analysis, skin on vs. skin off, and whole fillet analysis vs. dorsal plug analysis respectively. For this reason, only general comparisons between GLNPO and OMOE data should be made.

<u>Consumption advisories and PCB concentrations in coho salmon (U.S. program)</u>

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

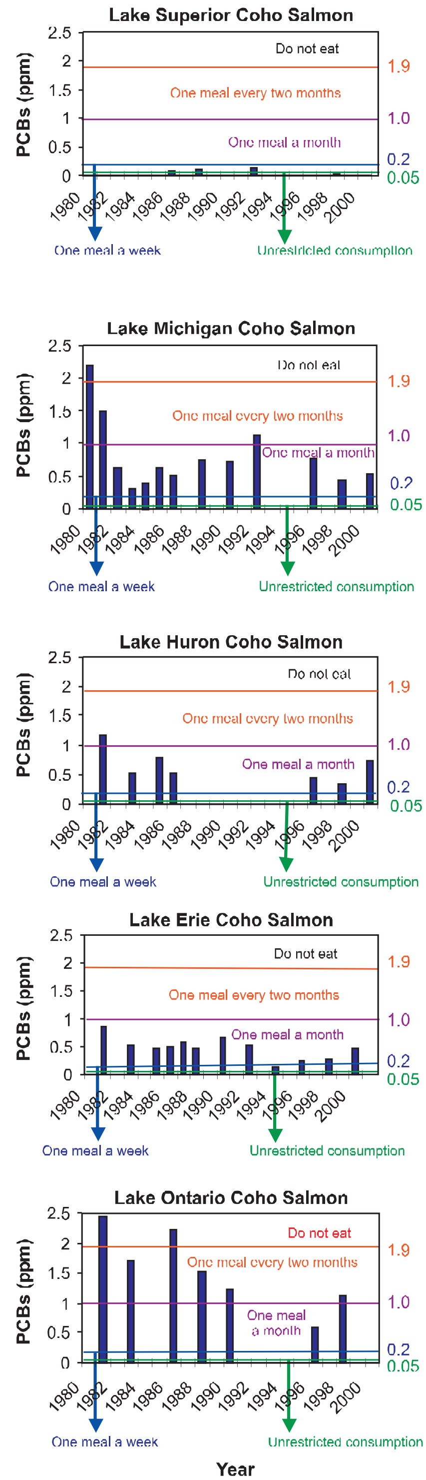

Figure 1. Results of a uniform fish advisory protocol applied to historical data (PCBs, coho salmon) in the Great Lakes. Blank indicates no sampling.
Source: Sandra Hellman, U.S. Environmental Protection Agency, Great Lakes National Program Office

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.

The application of a uniform fish advisory protocol to historical data of PCB concentrations in coho salmon illustrates the potential for identifying trends in the advisories (Figure 1). In the time period 1980-1981, advisories would have included "do not eat" for coho salmon from Lake Michigan and Lake Ontario, "one meal every two months" for coho from Lake Huron, and "one meal per month" for coho from Lake Erie. The most recent data (1998 or 2000) indicate improvements for Lake Michigan (one meal per month), Lake Ontario (one meal every two months), and Lake Huron (one meal per month). The advisory would remain the same for coho from Lake Erie (one meal per month). Only for coho from Lake Superior would the advisory be "unlimited consumption."

Illustration note - Please note that differing species (coho salmon and lake trout) and units (ppm and ppb) are presented in the accompanying graphs (Figure 1 and Figure 2). Typically lake trout have higher contaminant concentrations than coho salmon.

<u>Consumption advisories and PCB concentrations in lake trout (Canada program)</u>

The consumption advisories listed below are based only on total PCB concentrations. In many cases the consumption advice will be more restrictive than described below and will be based on dioxin toxic equivalents, which includes dioxins, furans and dioxin-like PCBs.

Lake Erie: Trend data are sparse for Lake Erie as lake trout are less abundant in this lake. PCB levels declined between 1984 and 2003 (Figure 2). 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.

Lake Huron: PCB levels in Lake Huron lake trout declined substantially between 1976 and 2002 (Figure 2). In 1976 concentrations exceeded 4 ppm, well above the "do not eat" consumption limit of 1.22 ppm for the general population. PCB concentrations are currently within the 4 meals per month range (0.153 ppm-0.305 ppm).

Lake Superior: PCB concentrations in Lake Superior lake trout have declined considerably over the period of record (Figure 2). In the late 1970s, PCB concentrations exceeded the current "do not eat" consumption limit. Since 1990, concentrations have generally fluctuated between 0.153 and 0.610 ppm, which would permit the consumption of either 2 or 4 meals per month.

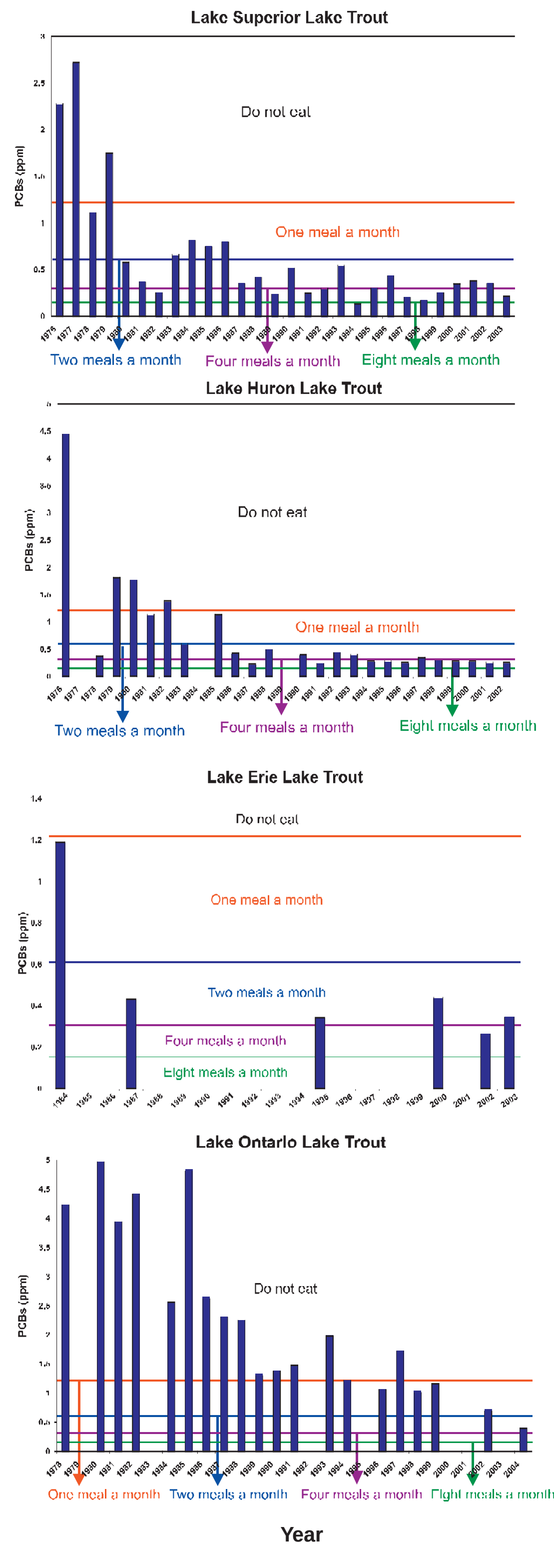

Figure 2. PCBs in lake trout, Ontario data.
Source: Ontario Ministry of the Environment

Lake Ontario: Historically, the highest concentrations of PCBs have been found in Lake Ontario. From the late 1970s to 1999, PCBs in (60 cm) lake trout from Lake Ontario usually exceeded the “do not eat” consumption limit (Figure 2). 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.

Lake Michigan: Ontario sport fish sampling is restricted to the Province of Ontario waters of the Great Lakes. No samples were collected from Lake Michigan.

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.

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. 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.

Acknowledgments

Authors: Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office;
Jackie Fisher, U.S. Environmental Protection Agency, Great Lakes National Program Office;
Emily Awad, Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment, Etobicoke, ON;
Alan Hayton, Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment, Etobicoke, ON; and
Patricia McCann, Minnesota Department of Health.

Contributor: Sandra Hellman, U.S. Environmental Protection Agency, Great Lakes National Program Office.

Sources

Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office, murphy.elizabeth@epa.gov.

De Vault, D.S. and Weishaar, J.A. 1984. *Contaminant analysis of 1982 fall run coho salmon*. U.S. Environmental Protection Agency, Great Lakes National Program Office. EPA 905/3-85-004.

De Vault, D.S. and Weishaar, J.A. 1983. *Contaminant analysis of 1981 fall run coho salmon*. U.S. Environmental Protection Agency, Great Lakes National Program Office. EPA 905/3-83-001.

De Vault, D.S., Weishaar, J.A., Clark, J.M., and Lavhis, G. 1988. Contaminants and trends in fall run coho salmon. *J. Great Lakes*

Res. 14:23-33.

Great Lakes Sport Fish Advisory Task Force. 1993. *Protocol for a uniform Great Lakes sport fish consumption advisory*. http://fn.cfs.purdue.edu/anglingindiana/HealthRisks/TaskForce.pdf, last accessed July 22, 2005.

Ontario Ministry of the Environment (OMOE). 2005. *Guide to Eating Ontario Sport Fish 2005-2006*. http://www.ene.gov.on.ca/envision/guide/index.htm, last accessed October 4, 2005.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington. http://www.on.ec.gc.ca/glwqa/.

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.

Authors' Commentary
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.

Air Quality

Indicator #4202

Note: This indicator replaces the old Air Quality indicator (#4176).

Assessment: Mixed, 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 2002 were the lowest recorded in the past 20 years. Ambient concentrations have decreased approximately 65% nationally from 1983 to 2002 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 more rapidly in the Great Lakes region than for the nation as a whole.

In Canada, there has been about a 60% reduction nationwide in the average ambient levels of CO from 1980 to 2000. Ontario has not experienced an exceedence of the 1-hour and 8-hour criteria since 1991. The composite average of the 1-hour and the 8-hour CO maximums has decreased 55% from 1993 to 2002. The composite annual mean has also decreased 29% over this same period.

Emissions: In the U.S., nationwide emissions of CO have decreased 41% from 1983 to 2002 and 21% from 1993 to 2002 despite a 155% increase in vehicle miles traveled since 1970. The reductions are much more than those reported in the State of the Great Lakes 2003 (SOGL) report due to improvements in the emissions inventories.

In Canada, emissions have decreased nationally by 17% since 1988 with a 4% decline in Ontario between 1991 and 2000. These declines are mainly the result of more stringent transportation emission standards.

Nitrogen Dioxide (NO_2)

Ambient Concentrations: In Canada, annual average hourly NO_2 concentrations show a slight downward trend from 1991 to 2000. Ontario's annual mean concentrations declined about 23% from 1975 to 2002 and about 10% from 1993 to 2002. The air quality criterion for NO_2 was not exceeded at any of Ontario's monitoring stations in 2001 or 2002.

In the U.S., the annual mean concentrations decreased 21% from 1983 to 2002 and decreased 11% from 1993 to 2002. NO_2 levels in the Great Lakes region have decreased 19% from 1982 to 2001, with the majority of the improvement occurring in the 1980s. 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 NO_2 in urban areas (similar results can be found in Ontario). There are currently no NO_2 nonattainment areas in the

U.S.

Emissions: Trends in emissions of the family of nitrogen oxides (NO_x) in Canada are unknown at this time, although significant reductions have been accomplished from the transportation sector.

In the U.S., emissions of NO_x decreased by about 15% from 1983 to 2002 and decreased by about 12% from 1993 to 2002. This trend is much different from the increase reported in the SOGL 2003 report due to new and improved emission estimates for highway vehicles and non-road engines. (For more information on oxides of nitrogen, please refer to the Great Lakes Indicator Report #9000 Acid Rain.)

Sulfur Dioxide (SO_2)
Ambient Concentrations: In the U.S., annual mean concentrations of SO_2 decreased 54% from 1983 to 2002. From 1993 to 2002, annual mean concentrations of SO_2 in the U.S. decreased 39%. The Great Lakes region has experienced reducing trends on par with the national averages. There are two nonattainment areas in the Great Lakes region for SO_2 (Lake County, Indiana; and Cuyahoga County, Ohio). Since the SOGL 2003 Report, the U.S. Environmental Protection Agency (USEPA) approved the redesignation of Lucas County (Toledo), Ohio, to an attainment area.

Canada has experienced a 50% reduction nationwide in the average ambient levels of SO_2 from 1980 to 2000. In Ontario, the average ambient concentrations improved 84% from 1971 to 2002, with a 20% improvement since 1993. Ontario experienced only two violations of the one-hour criterion of 250 ppb in 2001 and also in 2002 (Sarnia and Sudbury).

Emissions: In the U.S., national SO_2 emissions were reduced 33% from 1983 to 2002 and 31% from 1993 to 2002 mostly in response to regulations imposing cuts on coal-burning power plants.

Canadian emissions decreased 45% nationwide from 1980 to 2000, but have remained relatively constant since 1995. Even with increasing economic activity, emissions remain about 20% below the target national emission cap. From 1971 to 2001, the emissions of SO_2 in Ontario decreased 82%. 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 94% from 1983 to 2002 and 57% from 1993 to 2002. 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.

Lead concentrations at urban monitoring stations in Ontario have decreased over 95% from 1984 to 2000.

Emissions: National lead emissions in the U.S. decreased 93% from 1982 to 2002 as a result of regulatory efforts to reduce the content of lead in gasoline, but decreased only 5% from 1993 to 2002.

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. There is no apparent trend in the annual average concentrations of TRS in Ontario from 1993 to 2002. There are still periods above the ambient criteria near a few centres.

PM_{10}
Ambient Concentrations: PM_{10} is the fraction of particles in the atmosphere with a diameter of 10 microns or smaller. Ambient concentrations in the U.S. have decreased 13% from 1993 to 2002. Levels in the Great Lakes region have fallen by about 12% from 1992 to 2001. There are currently two nonattainment areas in the Great Lakes region (both in Cook County, Illinois). Since the SOGL 2003 report, the USEPA approved the redesignation of Lake County, Indiana, to an attainment area.

Canada does not have an ambient target for PM_{10}. However, Ontario has an interim standard of 50 $\mu g/m^3$ over a 24-hour sampling period.

Emissions: In the U.S., national direct source man-made emissions decreased 34% from 1985-2002 and 22% from 1993 to 2002.

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 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 47% in the U.S. from 1994 to 2000.

In Ontario, average annual urban concentrations of benzene have decreased 56% from 1993 to 2002. The average annual urban concentrations in Ontario of toluene and o-xylene (aromatic hydrocarbons) have decreased 44% and 59% respectively, over the same time period. Ontario data also show similar decreasing trends in the concentrations of 1,1,1-trichloroethane, carbon tetrachloride and dichloromethane (three common solvents) over the same period.

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 and 2001 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 were reported through the ARET program through 2000.

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. toxic emissions have dropped approximately 24% between the baseline years (1990-1993) and 1996, though emission estimates are subject to modification and the trends are different for different compounds. 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 75% from 1988 to 2002.

Regional Pollutants

Ground-Level Ozone (O_3)

Ozone is almost entirely a secondary pollutant, which forms from reactions of precursors (VOCs - volatile organic compounds and NO_x - 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 2003, ozone levels in the U.S. were the lowest they have been in over 20 years, however the improved air quality was mainly a result of favorable weather conditions. 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 are a result of local emission reductions in urban areas. On the other hand, ozone concentrations in rural areas have remained relatively stable with some slight increases.

There are six nonattainment areas in the Great Lakes basin for the 1-hour ozone standard (Chicago metropolitan area, IL; Lake and Porter Counties, IN; Milwaukee-Racine metropolitan area, WI; Erie County, PA; Buffalo-Niagara Falls metropolitan area, NY; and Jefferson County, NY). Since the SOGL 2003 report, Manitowoc and Door Counties in Wisconsin were redesignated to attainment areas for the 1-hour ozone standard. In addition, the USEPA recently designated 28 areas covering 70 counties as nonattainment for the 8-hour ozone standard in the Great Lakes basin (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;

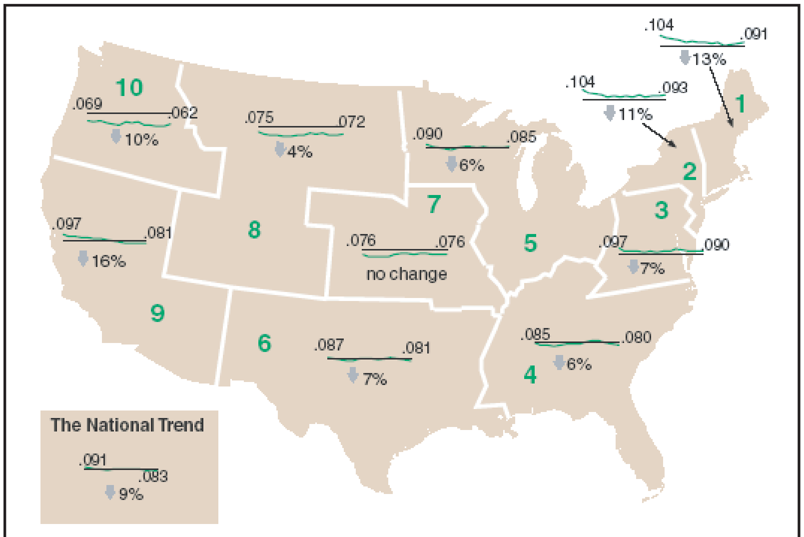

Figure 1. Trend in fourth highest daily maximum 8-hour ozone concentration (ppm) by EPA Region, 1990-2003.
Source: Figure 15 of U.S. Environmental Protection Agency. 2004. The Ozone Report: measuring progress through 2003. Office of Air Quality Planning and Standards. EPA-454/K-04-001.
http://www.epa.gov/airtrends/ozone.html

Lansing-East Lansing metro area, MI; Benton Harbor area, MI; Benzie County, MI; Cass County, MI; Mason County, MI; Toledo metro area, OH; Cleveland-Akron-Lorain metro area, OH; Erie, PA; Jamestown, NY; Buffalo-Niagara Falls metro area, NY; Rochester metro area, NY; and Jefferson County, NY).

In Ontario, ozone concentrations continue to exceed Ontario's Ambient Air Quality Criterion (AAQC). In 2002, 39 out of the 40 monitoring sites in Ontario recorded exceedences of the 1-hour AAQC on at least one occasion. Although the ozone levels continue to exceed Ontario's AAQC, the maximum ozone concentrations recorded in Ontario have, on average, decreased from 1980 to 2002 (Figure 2). This trend may indicate that 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 23-year period. The summer and winter seasonal ozone means have increased by approximately 23% and 27%, 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 (65 ppb averaged over 8 hours) until 2006, data in 2002 indicate that all but one monitoring site in Ontario recorded at least one day with levels that exceeded 65 ppb. In eastern Canada as a whole, the annual 4th highest daily maximum 8-hour concentration shows little change from 1991 to 2000.

Emissions: In the U.S., VOC emissions have decreased 48% from 1980 to 2003 and 32% from 1990 to 2003. NO_x emissions in the U.S. have also decreased 27% from 1980 to 2003 and 22% from 1990 to 2003.

In Ontario, man-made VOC emissions have decreased about 13 percent from 1992 to 2001. However, VOC emissions in all of Canada have remained relatively constant from 1991 to 2000. Canadian NO_x emissions have remained fairly constant since 1990, although significant reductions have been accomplished from the transportation sector.

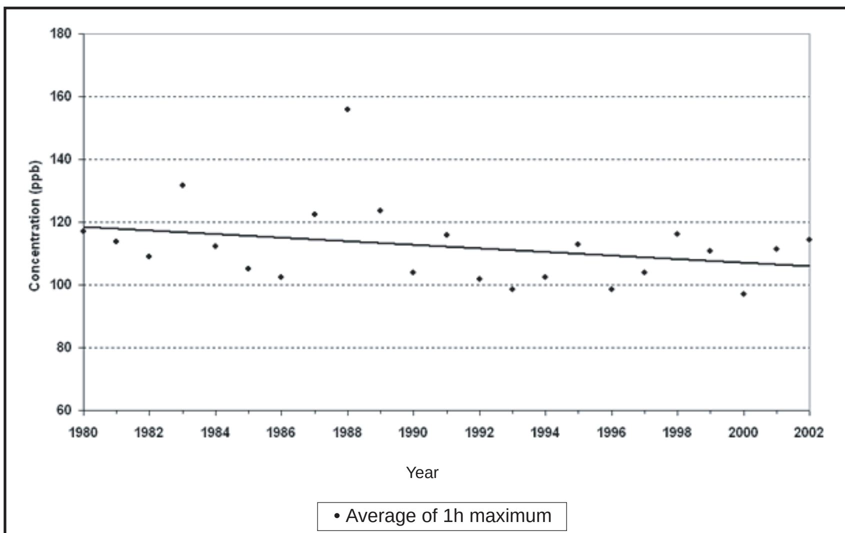

Figure 2. Mean 1-hour maximum ozone concentrations in Ontario from 1980 to 2002.
Source: Figure 2.4 of Ontario Ministry of the Environment. Air Quality in Ontario 2002 Report. Queen's Printer for Ontario, 2004.
http://www.ene.gov.on.ca/envision/etchdocs/4521e01.pdf

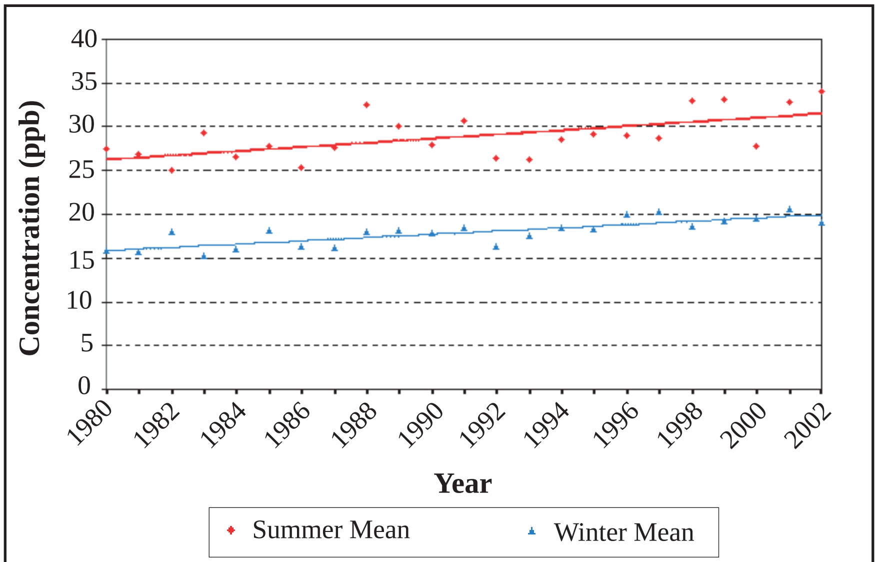

Figure 3. Summer and winter seasonal ozone mean concentrations from 1980 to 2002.
Source: Figure 2.5 of Ontario Ministry of the Environment. Air Quality in Ontario 2002 Report. Queen's Printer for Ontario, 2004. http://www.ene.gov.on.ca/envision/techdocs/4521e01.pdf

$PM_{2.5}$

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 (SO_2, NO_X, and ammonia).

Ambient Concentrations: A CWS for $PM_{2.5}$ of 30 µg/m^3 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 2002 indicate that seven out of 14 monitoring sites across Ontario recorded 98th percentile daily averages of $PM_{2.5}$ above 30 µg/m^3. Data from 2001 show similar patterns, with nine out of 20 monitoring sites above 30 µg/m^3.

In a preliminary assessment of data from the U.S. $PM_{2.5}$ monitoring network, it appears that concentrations in urban areas are higher than in rural areas. The average annual concentration of $PM_{2.5}$ has decreased 8% from 1999 to 2002. This decreasing trend is mostly attributable to reductions in SO_2 emissions as a result of Phase II of the Acid Rain Program. The particulate matter of the Great Lakes region generally has larger fractions of nitrates and carbon than national averages. Therefore, the Great Lakes region probably experienced less of a decrease in $PM_{2.5}$ concentrations. In June 2004, the USEPA issued preliminary designations for the $PM_{2.5}$ standard. Five areas in the Great Lakes region were preliminarily designated nonattainment including the Chicago-Gary-Kenosha, IL-IN-WI metropolitan area; Elkhart and St. Joseph Counties, IN; Detroit-Ann Arbor, MI metro area; Toledo, OH metro area; and the Cleveland-Akron-Lorain, OH metro area.

Emissions: In the U.S., direct emissions of $PM_{2.5}$ from anthropogenic sources decreased 17% nationally from 1993 to 2002, however this decreasing trend does not account for the formation of secondary particles.

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 NO_X 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 NO_X 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 NO_X and VOCs by 45% of 1990 levels by 2015, with interim targets of 25% by 2005.

The U.S. estimates that the total NO_X 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. $PM_{2.5}$ 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.

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Sources

Environment Canada. 2004. *2002 National Pollutant Release Inventory Data.* http://www.ec.gc.ca/pdb/npri/npri_dat_rep_e.cfm#highlights, last accessed June 29, 2004.

Environment Canada. 2003a. *2001 National Pollutant Release Inventory: national overview.* http://www.ec.gc.ca/pdb/npri/npri_dat_rep_e.cfm#annual2001, last accessed June 29, 2004.

Environment Canada. 2003b. *Clean air in Canada: 2003 progress report on particulate matter and ozone.* ISBN 0-662-34514-2. http://www.ec.gc.ca/air/PM_resp_03/PM_resp_03_e.pdf, last accessed April 17, 2004.

Environment Canada. 2003c. *Cleaner air through cooperation: Canada – United States progress under the Air Quality Agreement 2003*. ISBN 0-662-34082-5. http://www.epa.gov/airmarkets/usca/brochure/brochure.htm, last accessed April 17, 2004.

Environment Canada. 2003d. *Environment Canada Performance Report: for the period ending March 31, 2003.* David Anderson, Minister of the Environment. http://www.ec.gc.ca/dpr/EC_DPR_March_31_2003_EN-Oct6.pdf, last accessed June 17, 2004.

Environment Canada. 2003e. *Environmental signals: Canada's national environmental indicator series 2003.* http://www.ec.gc.ca/soer-ree/English/Indicator_series/default.cfm#pic, last accessed July 29, 2004.

Environment Canada. *National Air Pollution Surveillance Network*. http://www.etc-cte.ec.gc.ca/NAPS/, last accessed June 29, 2004.

Great Lakes Commission. *Great Lakes Regional Air Toxics Emissions Inventory.* http://www.glc.org/air/air3.html, last accessed June 25, 2004.

NARSTO. 2000. *An assessment of tropospheric ozone: a North American perspective.* http://www.cgenv.com/Narsto/, last accessed June 30, 2004.

Ontario Ministry of the Environment (OMOE). 2004. *Air quality in Ontario 2002 report.* Queen's Printer for Ontario. http://www.ene.gov.on.ca/envision/techdocs/4521e01.pdf, last accessed June 28, 2004.

Ontario Ministry of the Environment (OMOE). 2003. *Air quality in Ontario 2001 report*. Queen's printer for Ontario. http://www.ene.gov.on.ca/envision/air/AirQuality/2001.htm, last accessed June 17, 2004.

U.S. and Canada. *Canada-United States Air Quality Agreement: 2002 progress report*. http://www.epa.gov/airmarkets/%20usca/airus02.pdf, last accessed June 17, 2004.

U.S. Environmental Protection Agency (USEPA). 2004a. *8-Hour ground-level ozone designations*. http://www.epa.gov/ozonedesignations/, last accessed July 8, 2004.

U.S. Environmental Protection Agency (USEPA). 2004b. *Fine particle (PM2.5) designations.* http://www.epa.gov/pmdesignations/, last accessed July 8, 2004.

U.S. Environmental Protection Agency (USEPA). 2004c. *Green* *book: non-attainment areas for criteria pollutants.* Office of Air Quality Planning and Standards. http://www.epa.gov/air/oaqps/greenbk/, last accessed June 17, 2004.

U.S. Environmental Protection Agency (USEPA). 2004d. *Technology transfer network: ambient monitoring technology information center.* http://www.epa.gov/ttn/amtic/airtoxpg.html, last accessed July 14, 2004.

U.S. Environmental Protection Agency (USEPA). 2004e. *The ozone report: measuring progress through 2003.* Office of Air Quality Planning and Standards. EPA-454/K- 04-001. http://www.epa.gov/airtrends/ozone.html, last accessed June 17, 2004.

U.S. Environmental Protection Agency (USEPA). 2004f. *Toxics Release Inventory Program*. http://www.epa.gov/tri/, last accessed June 24, 2004.

U.S. Environmental Protection Agency (USEPA). 2003a. *1999 National emissions inventory documentation and data.* http://www.epa.gov/ttn/chief/net/1999inventory.html.

U.S. Environmental Protection Agency (USEPA). 2003b. *EPA's draft report on the environment: technical document*. EPA-600-R-03-050. http://www.epa.gov/indicators/, last accessed June 30, 2004.

U.S. Environmental Protection Agency (USEPA). 2003c. *Latest findings on national air quality: 2002 status and trends*. Office of Air Quality Planning and Standards. EPA-454/K-03-001. http://www.epa.gov/airtrends/2002_airtrends_final.pdf, last accessed June 17, 2004.

U.S. Environmental Protection Agency (USEPA). 2003d. *National air quality and emissions trends report: 2003 special studies edition.* Office of Air Quality Planning and Standards. EPA-454/R-03-005. http://www.epa.gov/air/airtrends/aqtrnd03/, last accessed June 17, 2004.

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.

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Authors: Donald G. Uzarski, Annis Water Resources Institute, Grand Valley State University, Lake Michigan Center, 740 W. Shoreline Dr., Muskegon, MI, 49441; and
Thomas M. Burton, Departments of Zoology and Fisheries and Wildlife, Michigan State University, East Lansing, MI, 48824.

Sources

Environment Canada and Central Lake Ontario Conservation Authority. 2004. *Durham Region Coastal Wetland Monitoring Project: year 2 technical report.* Downsview, ON. ECB-OR.

Uzarski, D.G., Burton, T.M., and Genet, J.A. 2004. Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline. *Aquat. Ecosystem Health & Manage.* 7(2):269-288.

Wilcox, D.A., Meeker, J.E., Hudson, P.L., Armitage, B.J., Black, M.G., and Uzarski, D.G. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: a Great Lakes evaluation. *Wetlands* 22(3):588-615

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.

Coastal Wetland Fish Community Health

Indicator #4502

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.

Assessment: Not Assessed

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. Thus, the state of the ecosystem could not be determined using the wetland fish community health indicator during the last 2 years.

Teams of Canadian and American researchers from several research groups (e.g. the Wetlands Research Consortium of the Great Lakes Commission, the U.S. Environmental Protection Agency (USEPA) Star Grant-funded Great Lakes Environmental Indicators Group in Duluth, MN, a group of Great Lakes Fishery Commission researchers led by Patricia Chow-Fraser of McMaster University, the USEPA Regional Environmental Monitoring and Assessment Program (REMAP) group of researchers led by Tom Simon, and others) sampled large numbers of Great Lakes wetlands during the last 3 years. They have reported on an array of fish communities in Great Lakes wetlands in presentations at international meetings and in reports, but most of these data have not yet been published in refereed journals.

The composition of fish communities was significantly related to plant community type within wetlands and, within plant community type, was related to amount of anthropogenic disturbance (Uzarski *et al.* In Press). Uzarski *et al*. found no relationship 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, Dennis Albert, personal communication), and the fish communities found in cattails tended to have lower richness and diversity than fish communities found in other vegetation types. 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.

John Brazner and co-workers from the USEPA 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 (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 diaphanous*) in 1995 and 2003 compared with 1991, and white perch were very abundant in 1995, as this non-native 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 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, MN, 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 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 (J. Brazner, personal observation; Uzarski *et al.* In Press). 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.* 1992).

Ruffe (*Gymnocephalus cernuus*) 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 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 it 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 (U.S. Fish and Wildlife Service 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 they 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

Authors: Donald G. Uzarski, Annis Water Resources Institute, Grand Valley State University, Lake Michigan Center, 740 W. Shoreline Dr., Muskegon, MI, 49441;
Thomas M. Burton, Departments of Zoology and Fisheries and Wildlife, Michigan State University, East Lansing, MI, 48824;
John Brazner, U.S. Environmental Protection Agency, Mid-Continent Ecology Division, 6201 Congdon Blvd., Duluth, MN, 55804; and
David Jude, School of Natural Resources and the Environment, 430 East University, University of Michigan, Ann Arbor, MI, 48109.

Sources

Brazner, J.C. 1997. Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. *J. Great Lakes Res.* 23(1):36-51.

Brazner, J.C., Tanner, D.K., Jensen, D.A., and Lemke, A. 1998. Relative abundance and distribution of ruffe (*Gymnocephalus cernuus*) in a Lake Superior coastal wetland fish assemblage. *J. Great Lakes Res.* 24(2):293-303.

Jude, D.J., and Pappas, J. 1992. Fish utilization of Great Lakes coastal wetlands. *J. Great Lakes Res.* 18(4):651-672.

Jude, D.J., Reider, R.H., and Smith, G.R. 1992. Establishment of Gobiidae in the Great Lakes basin. *Can. J. Fish. Aquat. Sci.* 49:416-421.

U.S. Fish and Wildlife Service. 2002. *Asian Carp, key to identification*. Pamphlet, 4 pp. La Crosse Fishery Resource Office, Onalaska, WI. www.iisgcp.org/il-ans.

Uzarski, D.G., Burton, T.M., Cooper, M.J., Ingram, J., and Timmermans, S. In Press. Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: Development of a fish based index of biotic integrity. *J. Great Lakes Res*.

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.

Coastal Wetland Amphibian Diversity and Abundance

Indicator #4504

Assessment: Mixed, Deteriorating

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

The ecosystem objective is 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 ensure population maintenance of each species and overall species diversity (Great Lakes Water Quality Agreement, Annex 13: United States and Canada 1987).

State of the Ecosystem

Background

Numerous amphibian species exist 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 surveys of calling amphibians are possible through coordination of volunteer naturalists skilled in the application of standardized monitoring protocols. Information about abundance, distribution and diversity of amphibians provides needed measures of their population trends and their habitat associations, and it can contribute to more effective, long-term conservation strategies.

Status of Amphibians

Since 1995, Marsh Monitoring Program (MMP) volunteers have collected amphibian data at 469 routes across the Great Lakes basin. Thirteen amphibian species were recorded during the 1995 – 2002 period. Spring Peeper was the most frequently detected species and was commonly recorded in full chorus (Call Level Code 3) when it was encountered (Table 1). Green Frog was detected in more than half of station-years and was most often recorded at Call Level Code 1. Grey Treefrog, American Toad and Northern Leopard Frog were also common, being recorded in more than one-third of all station years. Grey Treefrog was recorded with the second highest average calling code (1.9), indicating that MMP observers usually heard several individuals with some overlapping calls at each station. Bullfrog, Chorus Frog and Wood Frog were detected in approximately one-quarter of station-years, while the remaining five species were detected infrequently by MMP surveyors and were recorded in less than 3% of station-years.

Species	% Station - Years Present*	Average Calling Code
Spring Peeper	69.2	2.5
Green Frog	54.4	1.3
Grey Treefrog	39.1	1.9
American Toad	37.7	1.5
Northern Leopard Frog	31.6	1.3
Bullfrog	26.9	1.3
Chorus Frog	25.9	1.7
Wood Frog	18.6	1.5
Pickerel Frog	2.6	1.2
Blanchard's Cricket Frog	0.7	1.4
Cope's Grey Treefrog	1.7	1.4
Mink Frog	1.2	1.2
Fowlers Toad	2.6	1.4

* MMP survey stations monitored for multiple years considered as individual samples

Table 1. Frequency of occurrence (% Station-Years Present) and average Call Level Code for amphibian species detected inside Great Lakes basin MMP stations, 1995 through 2002. 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, too numerous to be estimated.
Source: Marsh Monitoring Program

Trends in amphibian occurrence were assessed for eight species commonly detected on MMP routes (Figure 1). For each species, the annual proportion of stations with that species present at each route was calculated to derive annual indices of occurrence. Overall temporal trend in occurrence for each species was assessed by combining route-level trends in station occurrence. Statistically significant declines in occurrence trends were detected for American Toad, Chorus Frog, Green Frog and Northern Leopard Frog.

These data will serve as baseline data with which to compare future survey results. Anecdotal and research evidence suggest 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 here (i.e., decline in American Toad, Chorus Frog, Green Frog

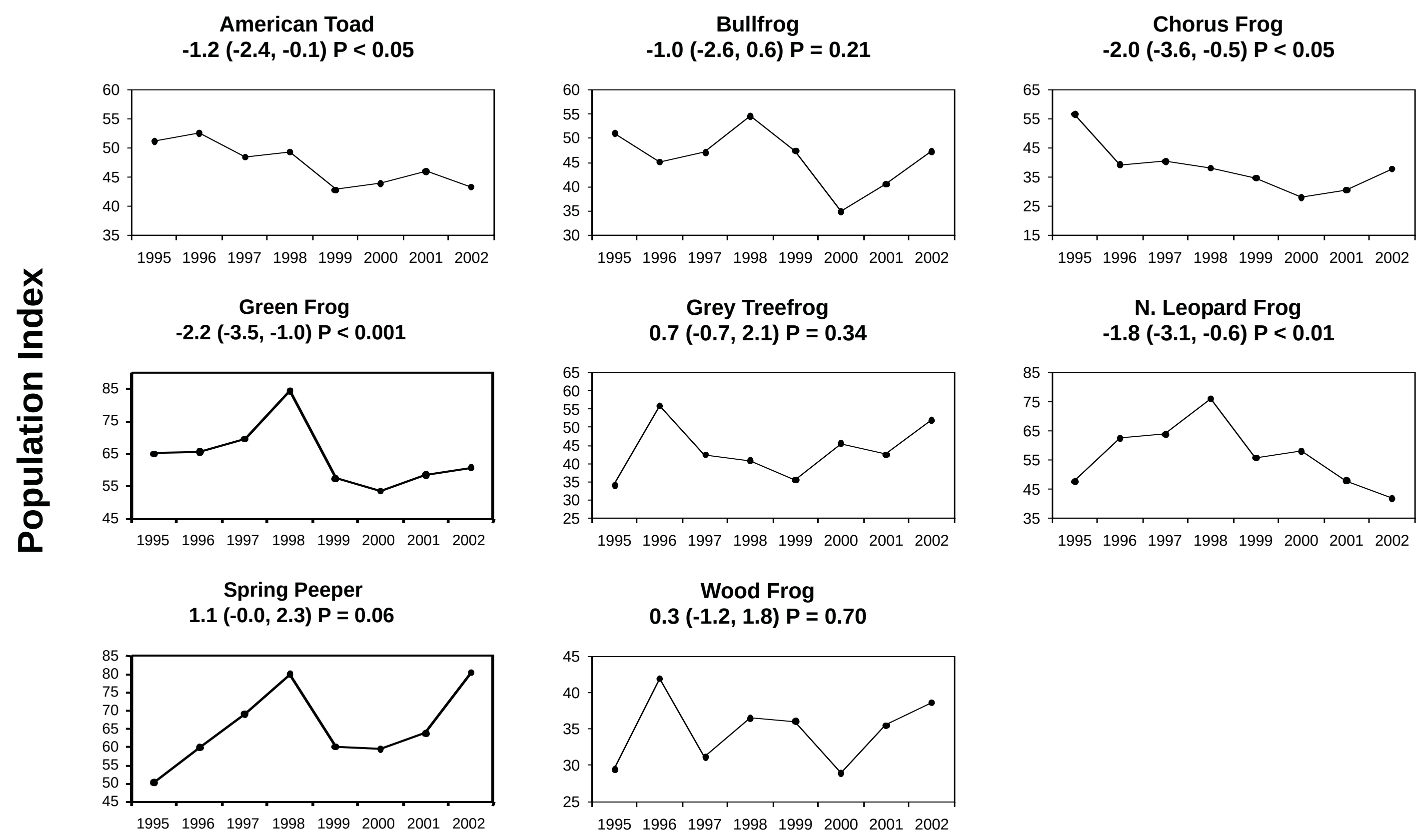

Figure 1. Trends (percent annual change) in station occurrence (population index) of eight amphibian species commonly detected at Marsh Monitoring Program routes, 1995-2002. Values in parentheses are upper and lower 95% confidence limits, respectively, for trend values given.
Source: Marsh Monitoring Program

and Northern Leopard Frog) indicate significant long-term trends or simply natural variation in population size. Further data are thus required to conclude whether Great Lakes wetlands are successfully sustaining amphibian populations. MMP amphibian data are being evaluated to determine how we can gain a better understanding of Great Lakes coastal wetlands condition.

Pressures
Habitat loss and deterioration remain the predominant threat to Great Lakes amphibian populations. Many coastal and inland Great Lakes wetlands are at the lowest elevations in watersheds that support very intensive industrial, agricultural and residential development, and therefore are under pressure through polluted inflow received from their watersheds. Even more subtle impacts such as water level stabilization, sedimentation, contaminant and nutrient inputs, climate change, and invasion of non-native species continue to degrade wetlands across the Great Lakes region.

Management Implications
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 wetland habitats as well as associated upland areas adjacent to coastal wetlands. There is also a need to address more subtle 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.

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Sources

Anonymous. 2003. *Marsh Monitoring Program training kit and instructions for surveying marsh birds, amphibians, and their habitats*. Revised in 2003 by Bird Studies Canada. 41pp.

Timmermans, S.T.A. 2002. *Quality Assurance Project Plan for implementing the Marsh Monitoring Program across the Great Lakes basin.* Prepared for U.S. Environmental Protection Agency, Great Lakes National Program Office. Assistance ID #GL2002-145.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington. http://www.ijc.org/rel/agree/quality.html.

Weeber, R.C. 2000. *The Marsh Monitoring Program Quality Assurance Project Plan.* Prepared for the U.S. Environmental Protection Agency, Great Lakes National Program Office. Assistance ID #GL975139-01-0. 22pp.

Weeber, R.C., and M. Valliantos (eds.). 2000. *The Marsh Monitoring Program 1995-1999: Monitoring Great Lakes wetlands and their amphibian and bird inhabitants.* Published by Bird Studies Canada in cooperation with Environment Canada and the U.S. Environmental Protection Agency.

Authors' Commentary

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 about five years would be appropriate because amphibian populations naturally fluctuate through time, and a five-year timeframe would likely be able to indicate noteworthy changes in populations. 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. Development of such a network is underway and three important tasks are already in progress: 1) developing the SOLEC amphibian indicator as an index for evaluating coastal wetland condition; 2) gaining precise geo-referenced locations for all MMP routes to enable future spatial analyses using remote sensing and; 3) continued recruitment efforts and training for volunteer participants. Further work is required to determine the relationship between calling codes used to record amphibian occurrence and count estimates.

Contaminants in Snapping Turtle Eggs

Indicator #4506

Assessment: Mixed, Trend Not Assessed

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).

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).

From 2001 to 2003, CWS collected snapping turtle eggs at or near seven AOCs: Detroit River, Hamilton Harbour, Niagara River (Ontario), St. Clair River, St. Lawrence River (Ontario), Toronto, and Wheatley Harbour AOCs, as well as two reference sites. Mean sum PCBs varied considerably throughout the lower Great Lakes, ranging 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) and Turkey Creek (Detroit River) (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). However, 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).

Flame retardants (polybrominated diphenyl ethers [PBDEs]) are one of the chemicals of emerging concern because they are bioaccumulative and 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

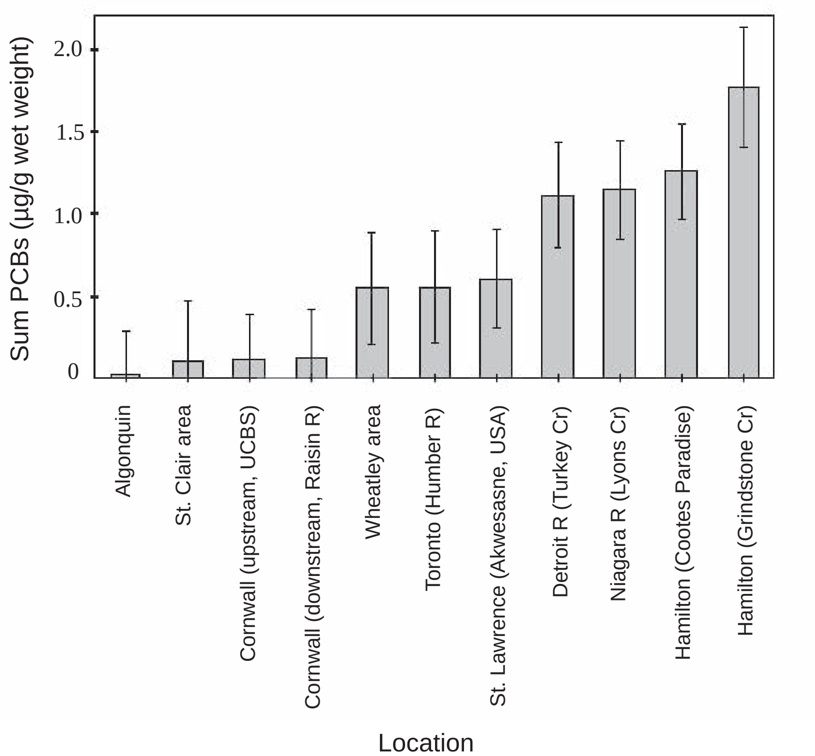

Figure 1. Sum PCB concentrations in snapping turtle eggs from various Canadian locations throughout the lower Great Lakes basin, 2001 through 2003. Means ± standard errors are presented.
Source: Canadian Wildlife Service

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. PAHs, PBDEs). 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 CWS are persistent and bioaccumulative, with diet being the primary source of exposure for snapping turtles. Thus, the contamination observed in the turtle eggs is present 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.

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Authors: Kim Fernie, Canadian Wildlife Service, Environment Canada, Burlington, ON, kim.fernie@ec.gc.ca; and
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Sources
Bishop, C.A., Brooks, R.J., Carey, J.H., Ng, P., Norstrom, R.J., and Lean, D.R.S. 1991. The case for a cause-effect linkage between environmental contamination and development in eggs of the common Snapping Turtle (*Chedlydra Ss. serpentina*) from Ontario, Canada. *J. Toxic. Environ. Health* 33:521-547.

Bishop, C.A., Ng, P., Norstrom, R.J., Brooks, R.J., and Pettit, K.E. 1996. Temporal and geographic variation of organochlorine residues in eggs of the common Snapping Turtle (*Chedlydra serpentina serpentina*) (1981-1991) and comparisons to trends in the herring gull (*Larus argentatus*) in the Great Lakes basin in Ontario, Canada. *Arch. Environ. Contam. Toxicol.* 31:512-524.

Bishop, C.A., Ng, P., Pettit, K.E., Kennedy, S.W., Stegeman, J.J., Norstrom, R.J., and Brooks, R.J. 1998. Environmental contamination and developmental abnormalities in eggs and hatchlings of the common Snapping Turtle (*Chedlydra serpentina serpentina*) from the Great Lakes-St. Lawrence River basin (1989-1991). *Environ. Pollut.* 101:143-156.

Struger, J., Elliott, J.E., Bishop, C.A., Obbard, M.E., Norstrom, R.J., Weseloh, D.V., Simon, M., and Ng, P. 1993. Environmental contaminants in eggs of the common Snapping Turtles (*Chedlydra serpentina serpentina*) from the Great Lakes-St. Lawrence River Basin of Ontario, Canada (1981, 1984).

Authors' Commentary

The 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.

Wetland-Dependent Bird Diversity and Abundance
Indicator #4507

Assessment: Mixed, Deteriorating

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.

Ecosystem Objective
Populations of Great Lakes coastal wetland bird communities should be self-sustaining and maintain species diversity. Breeding populations of bird species across their historical range should be sufficient to ensure population maintenance of each species and overall species diversity (Great Lakes Water Quality Agreement Annex 2).

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 believed to be at risk due to continuing 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 support birds and other wetland-dependent wildlife.

Geographically extensive and long-term surveys of wetland-dependent birds are possible through coordination of volunteer participants skilled in the application of standardized monitoring protocols. Information about abundance, distribution and diversity of marsh birds provides needed measures of their population trends and their habitat associations, and it can contribute to more effective, long-term conservation strategies.

Status of Wetland-Dependent Birds
From 1995 through 2002, 53 species of birds that use marshes (wetlands dominated by non-woody emergent plants) for feeding, nesting or both were recorded by Marsh Monitoring Program (MMP) volunteers at 419 routes throughout the Great Lakes basin. Among bird species that typically feed in the air above marshes, Tree Swallow and Barn Swallow were the two most common. Redwinged Blackbird was the most commonly recorded marsh nesting species, followed by Swamp Sparrow, Common Yellowthroat and Yellow Warbler.

With nine years of data collected across the Great Lakes basin, the MMP is still in its infancy as a long-term population monitoring program. Bird species' occurrence, abundance, activity and likelihood of being observed 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 2002 (Figure 1). Species with significant basin-wide declines were Least Bittern, Black Tern, Marsh Wren, undifferentiated American Coot/Common Moorhen (calls of these two species are difficult to distinguish from one another), Pied-billed Grebe, Red-winged Blackbird, and Virginia Rail. Statistically significant basin-wide population increases were observed for Willow Flycatcher (not shown), Common Yellowthroat, and Mallard. Barn Swallow populations did not show a significant trend. The observed declines in Least Bittern, Black Tern, American Coot/Common Moorhen, Marsh Wren, Pied-billed Grebe, and Virginia Rail, which use wetland habitats almost exclusively, combined with increases in some wetland edge and generalist species (e.g., Common Yellowthroat, Willow Flycatcher) suggest possible links to wetland habitat conditions.

To investigate whether marsh bird trends are linked to habitat conditions, water levels of the Great Lakes (see Effects of Water Level Fluctuations, indicator #4861) were used as a proxy for water conditions throughout the basin, and comparisons were made between trends in mean annual May-July water levels of the Great Lakes and trends in wetland bird annual abundance indices. In coastal wetlands of Lakes Erie and Michigan-Huron, population trends of American Coot, Least Bittern, Marsh Wren, Pied-billed Grebe, Sora, Swamp Sparrow, and Virginia Rail were positively correlated with water levels, and thus seemed to track fluctuations in Great Lakes water levels. American Bittern, Black Tern and Common Moorhen population abundance did not correlate well with water levels. Differences in habitats, regional population densities, timing of survey visits, annual weather variability, and other additional factors likely interplay with water levels to explain variation in species-specific bird populations.

Pressures
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 non-native plants and animals.

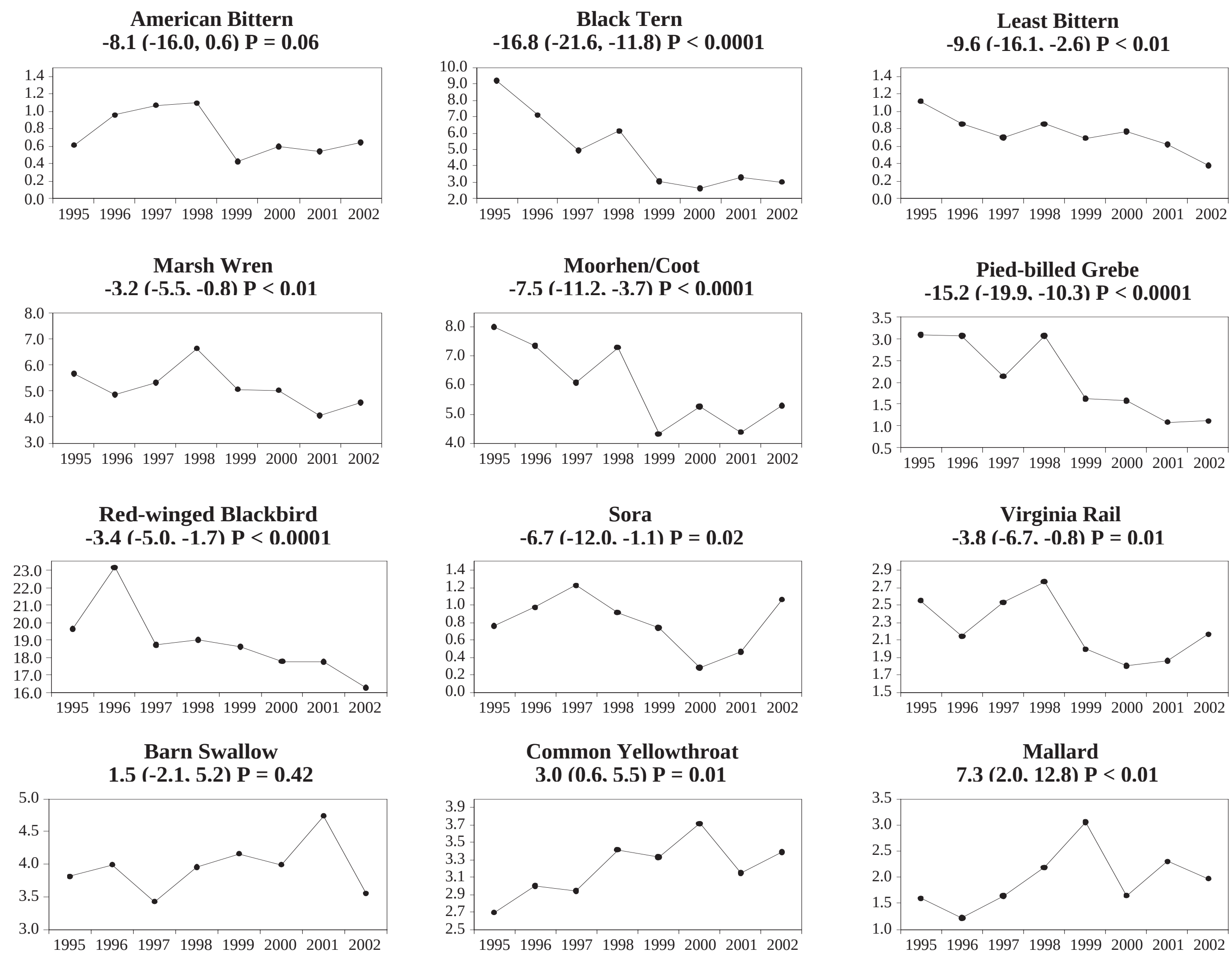


Figure 1. Trends (percent annual change) in relative abundance (population index) of marsh nesting and aerial foraging bird species detected at Marsh Monitoring Program routes, 1995-2002. Values in parentheses are upper and lower 95% confidence limits, respectively, for trend values given.
Source: Marsh Monitoring Program

Management Implications
Wherever possible, efforts should be made to maintain high quality wetland habitats and adjacent upland areas. There is also a need to address more subtle 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, further conservation and restoration work is needed.

Acknowledgments
Authors: Steve Timmermans, Bird Studies Canada; and Tara Crewe, Bird Studies Canada.

The Marsh Monitoring Program is delivered by Bird Studies Canada in partnership with Environment Canada and the U.S. Environmental Protection Agency, Great Lakes National Program Office. The contributions of all Marsh Monitoring Program volunteers are gratefully acknowledged.

Sources
Anonymous. 2003. *Marsh Monitoring Program training kit and instructions for surveying marsh birds, amphibians, and their*

habitats. Revised in 2003 by Bird Studies Canada.

Timmermans, S.T.A. 2002. *Quality Assurance Project Plan for implementing the Marsh Monitoring Program across the Great Lakes basin.* U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL. Assistance ID #GL2002-145.

Timmermans, S.T.A., Badzinski, S.S., and Jones, K.E. 2004. *The Marsh Monitoring Program annual report, 1995-2002: annual indices and trends in bird abundance and amphibian occurrence in the Great Lakes basin*. Bird Studies Canada.

Weeber, R.C. 2000. *The Marsh Monitoring Program Quality Assurance Project Plan.* U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL. Assistance ID #GL975139-01-0.

Weeber, R.C., and Valliantos, M. (eds.). 2000. *The Marsh Monitoring Program 1995-1999: monitoring Great Lakes wetlands and their amphibian and bird inhabitants*. Bird Studies Canada in cooperation with Environment Canada and the U.S. Environmental Protection Agency.

Authors' Commentary

Monitoring 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 the MMP. Recruitment and retention of program participants will therefore continue to be a high priority. Further work is necessary to establish endpoints and acceptable thresholds for bird diversity and abundance. Work is underway to ascertain marsh bird habitat associations using MMP bird and habitat data. Three additional important tasks are already in progress: 1) developing Great Lakes wetland bird indicator as an index for evaluating coastal wetland health; 2) gaining precise geo-referenced locations for all MMP routes to enable future spatial analyses using remote sensing, and; 3) continued recruitment efforts and training for volunteer participants. Assessments of relationships among count indices, bird population parameters, and critical environmental factors are also needed.

Although more frequent updates are possible, reporting trend estimates every five or six years is most appropriate for this indicator. A variety of efforts are underway to enhance reporting breadth and efficiency.

Coastal Wetland Area by Type

Indicator #4510

Assessment: Mixed, Deteriorating

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

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.

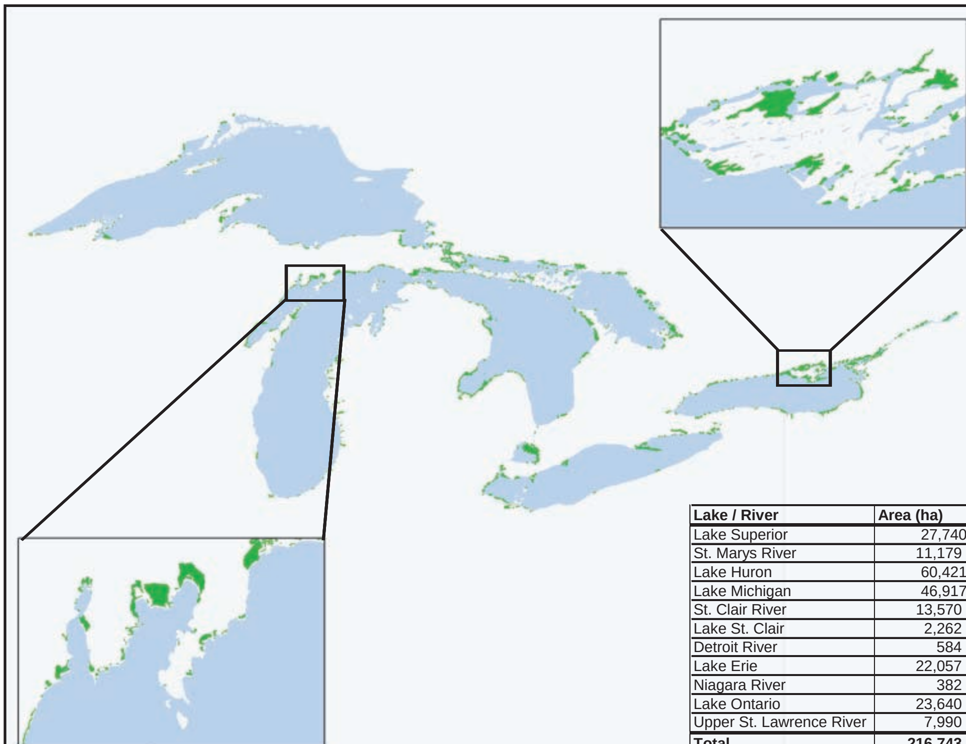
In an effort to estimate the current extent of coastal wetlands in the basin, the Great Lakes Coastal Wetland Consortium (GLCWC) recently coordinated completion of a binational coastal wetland database. The project involved building from existing Canadian and U.S. coastal wetland databases (Environment 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 also classified using a Great Lakes hydrogeomorphic coastal wetland classification system (Albert *et al.* 2005). 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



Lake / River	Area (ha)
Lake Superior	27,740
St. Marys River	11,179
Lake Huron	60,421
Lake Michigan	46,917
St. Clair River	13,570
Lake St. Clair	2,262
Detroit River	584
Lake Erie	22,057
Niagara River	382
Lake Ontario	23,640
Upper St. Lawrence River	7,990
Total	**216,743**

Figure 1. Great Lakes coastal wetland distribution and total area by lake and river.
Source: Great Lakes Coastal Wetlands Consortium

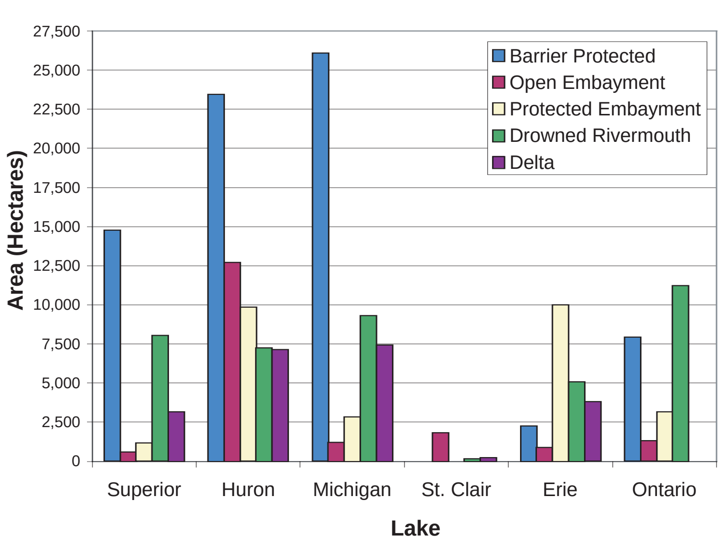


Figure 2. Coastal wetland area by geomorphic type within lakes of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

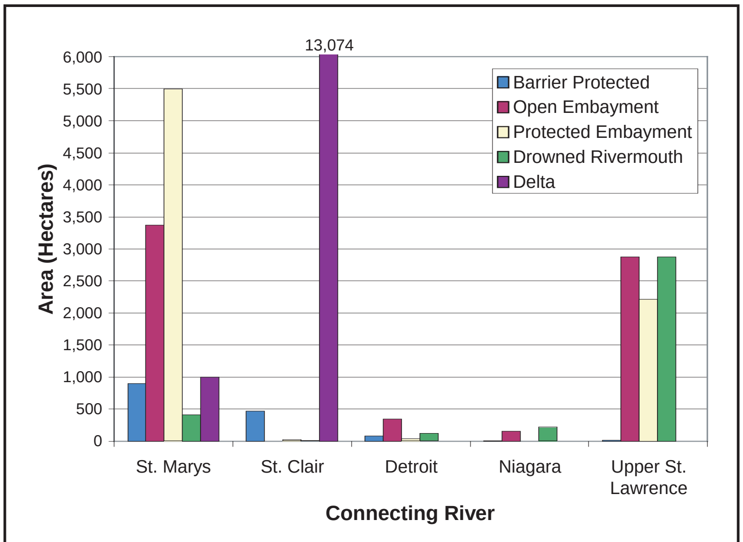


Figure 3. Coastal wetland area by geomorphic type within connecting rivers of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

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.

Acknowledgments

Authors: Joel Ingram, Canadian Wildlife Service, Environment Canada;
Lesley Dunn, Canadian Wildlife Service, Environment Canada; and
Dennis Albert, Michigan Natural Features Inventory, Michigan State University Extension.

Contributors: Krista Holmes and Nancy Patterson, Canadian Wildlife Service, Environment Canada; Laura Simonson, Water Resources Discipline, U.S. Geological Survey; Brian Potter, Conservation and Planning Section-Lands and Waters Branch, Ontario Ministry of Natural Resources; Tom Rayburn, Great Lakes Commission.

Sources

Albert, D.A., Wilcox, D.A., Ingram, J.W., and Thompson, T.A. accepted 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. *J. Great Lakes Res*.

Environment Canada and Ontario Ministry of Natural Resources. 2003. *The Ontario Great Lakes Coastal Wetland Atlas: a summary of information (1983 - 1997).* Canadian Wildlife Service (CWS), Ontario Region, Environment Canada; Conservation and Planning Section-Lands and Waters Branch, and Natural Heritage Information Center, Ontario Ministry of Natural Resources.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981a. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 1: Overview*. U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-81/02-v1.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981b. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 2: Lake Ontario*. U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-81/02-v2.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981c. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 3: Lake Erie.* U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-81/02-v3.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981d. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 4: Lake Huron.* U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-81/02-v4.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981e. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 5: Lake Michigan.* U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-81/02-v5.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981f. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 6: Lake Superior.* U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-81/02-v6.

Authors' Commentary

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.

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.

Ice Duration on the Great Lakes

Indicator #4858

This indicator report is from 2003.

Assessment: Mixed, 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).

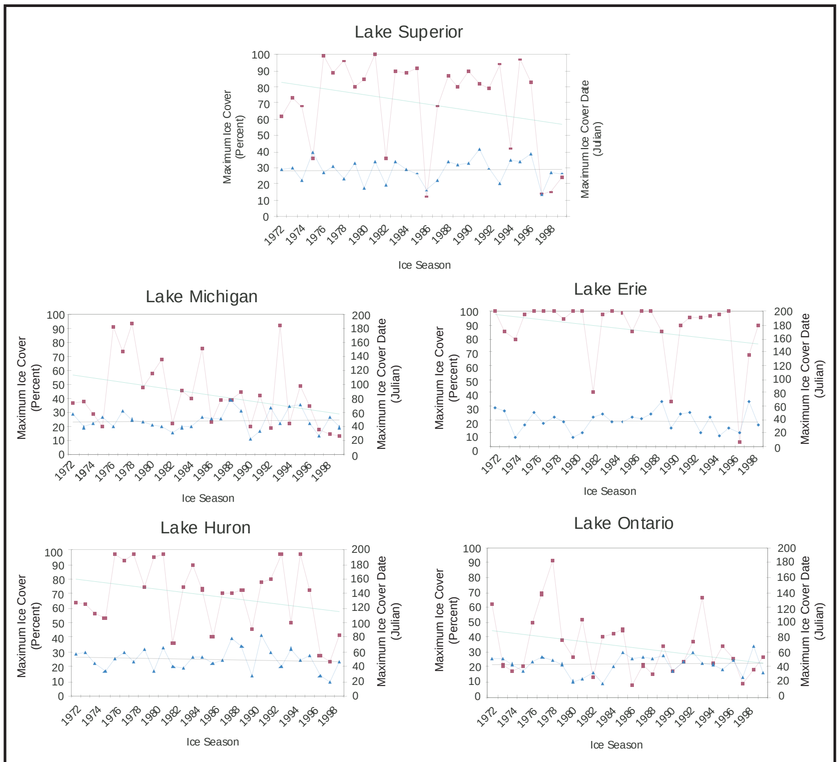


Figure 1. Trends of maximum ice cover and the corresponding date on the Great Lakes, 1972-2000. The red line represents the percentage of maximum ice cover and the blue line represents the date of maximum ice cover. Source: National Oceanic and Atmospheric Administration

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).

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.

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

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. The more data that are received will increase the statistical significance of the results.

Acknowledgments

Author: Gregg Ferris, Environment Canada Intern, Downsview, ON.
All data analyzed and charts created by the author.

Sources

Magnuson, J.J., Robertson, D.M., Benson, B.J., Wynne, R.H., Livingston, D.M., Arai, T., Assel, R.A., Barry, R.G., Carad, V., Kuusisto, E., Granin, N.G., Prowse, T.D., Stewart, K.M., and Vuglinski, V.S. 2000. Historical trends in lake and river ice covering the Northern Hemisphere. *Science* 289(Sept. 8):1743-1746.

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

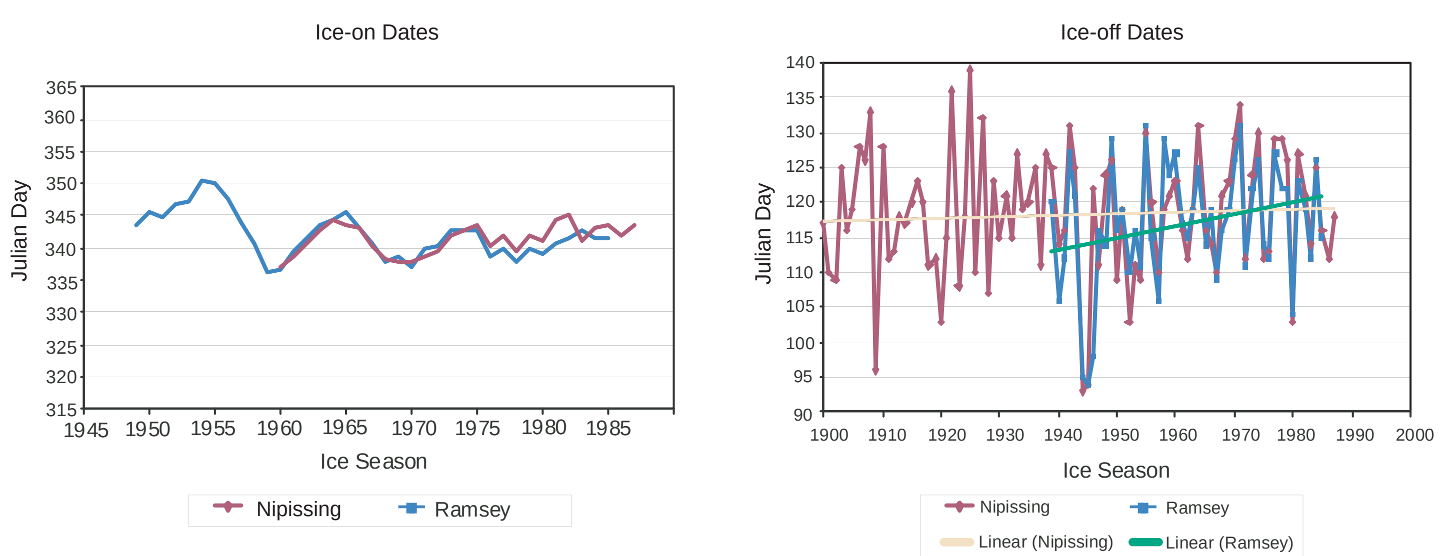


Figure 2. Ice-on and ice-off dates for Lake Nipissing (red line) and Lake Ramsey (blue line). Data were smoothed using a 5-year moving average.
Source: Climate and Atmospheric Research and Environment Canada

Canada-Ontario Region.

Authors' Commentary
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. The most substantial of these is the Kyoto Protocol, which looks at decreasing the emissions of greenhouse gases by 2008, with a large amount of attention on decreasing carbon dioxide. Countries that have not agreed to adhere to this protocol are taking other measures to reduce their emissions.

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.

Effect of Water Level Fluctuations

Indicator #4861

This indicator report is from 2003.

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 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.

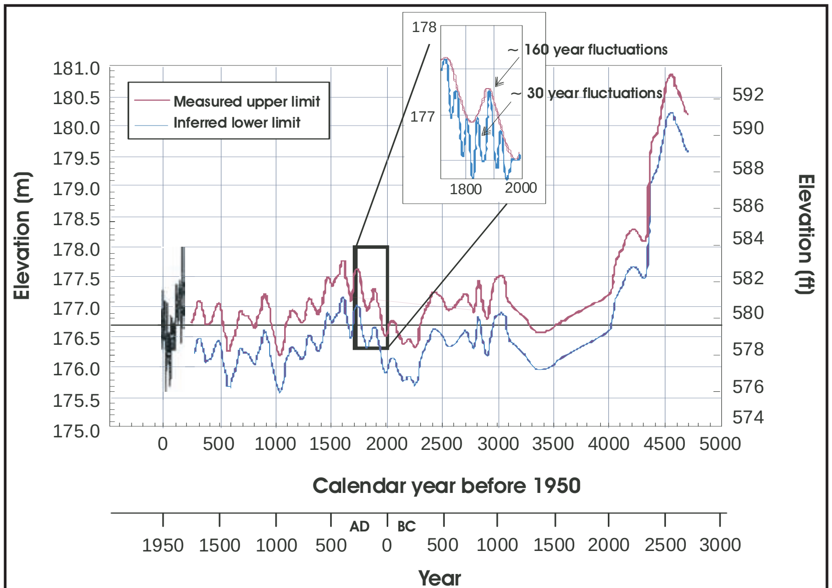


Figure 1. Sediment investigations on the Lake Michigan-Huron system indicates quasi-periodic lake level fluctuations.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

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

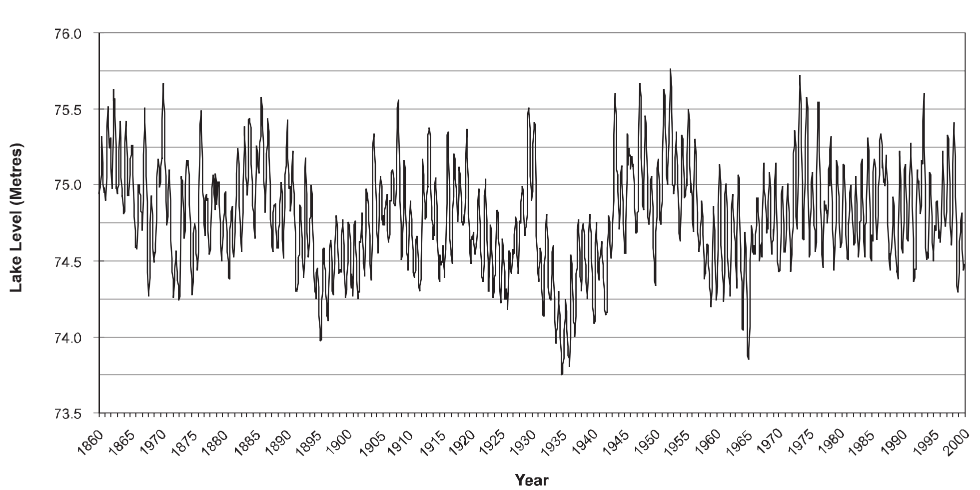


Figure 2. Actual water levels for Lake Ontario. IGLD-International Great Lakes Datum. Zero for IGLD is Rimouski, Quebec, at the mouth of the St. Lawrence River. Water level elevations in the Great Lakes/St. Lawrence River system are measured above water level at this site.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

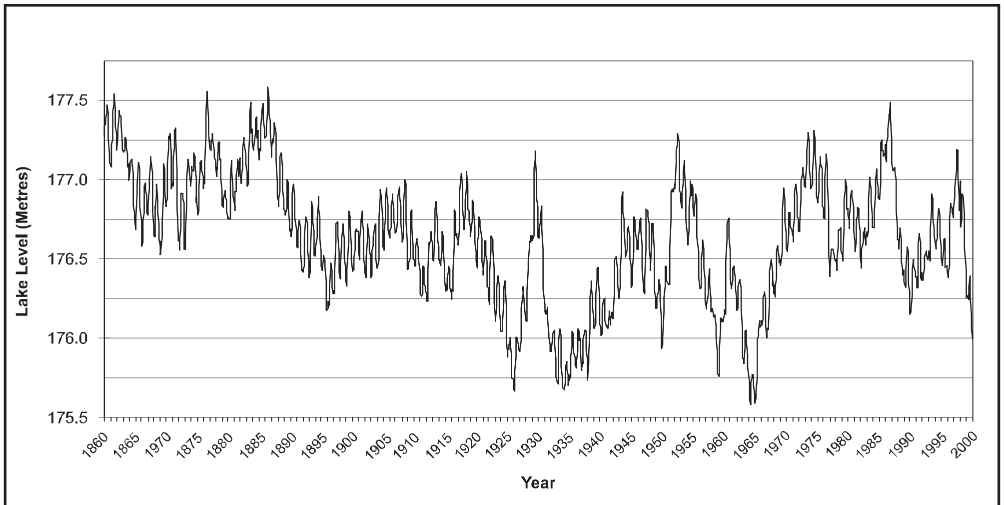


Figure 3. Actual water levels for Lakes Huron and Michigan. IGLD-International Great Lakes Datum. Zero for IGLD is Rimouski, Quebec, at the mouth of the St. Lawrence River. Water level elevations in the Great Lakes/St. Lawrence River system are measured above water level at this site.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

variation, the wetland zone would be much narrower and less diverse. Even very short-term fluctuations resulting from 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).

Sources
Baedke, S.J., and Thompson, T.A. 2000. A 4,700-year record of lake level and isostasy for Lake Michigan. *J. Great Lakes Res.* 26(4):416-426.

International Joint Commission. Great Lakes Regional Office, Windsor, ON and Detroit, MI.

International Lake Ontario-St. Lawrence River Study Board, Technical Working Group on Environment/Wetlands. http://www.ijc.org.

Maynard, L., and Wilcox, D. 1997. *Coastal wetlands of the Great Lakes*. State of the Lakes Ecosystem Conference 1996 Background Paper. Environment Canada and U.S. Environmental Protection Agency.

National Oceanic and Atmospheric Administration (NOAA). 1992 (and updates). *Great Lakes water levels, 1860-1990.* National Ocean Service, Rockville, MD.

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.

Coastal Wetland Plant Community Health

Indicator #4862

Assessment: Mixed, Undetermined

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).

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. 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

Sources

Albert, D.A., and Minc, L.D. 2001. Abiotic and floristic characterization of Laurentian Great Lakes' coastal wetlands. Stuttgart, Germany. *Verh. Internat. Verein. Limnol.* 27:3413-3419.

Albert, D.A., Wilcox, D.A., Ingram, J.W., and Thompson, T.A. In Press. Hydrogeomorphic Classification for Great Lakes Coastal Wetlands. *J. Great Lakes Res.*

Environment Canada and Central Lake Ontario Conservation Authority. 2004. *Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report.* Environment Canada, Downsview, ON: ECB-OR.

Herdendorf, C.E. 1988. *Classification of geological features in Great Lakes nearshore and coastal areas.* Protecting Great Lakes Nearshore and Coastal Diversity Project. International Joint Commission and The Nature Conservancy, Windsor, ON.

Herdendorf, C.E., Hakanson, L., Jude, D.J., and Sly, P.G. 1992. A review of the physical and chemical components of the Great Lakes: a basis for classification and inventory of aquatic habitats. In *The development of an aquatic habitat classification system for lakes*., eds. W.-D. N. Busch and P. G. Sly, pp. 109-160. Ann Arbor, MI: CRC Press.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981a. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 1: Overview*. U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS- 81/02-v1.

Jaworski, E., Raphael, C.N., Mansfield, P.J., and Williamson, B.B. 1979. *Impact of Great Lakes water level fluctuations on coastal wetlands.* U.S. Department of Interior, Office of Water Resources and Technology, Contract Report 14-0001-7163, from Institute of Water Research, Michigan State University, East Lansing, MI, 351pp.

Keough J.R., Thompson, T.A., Guntenspergen, G.R., and Wilcox, D.A. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands* 19:821-834.

Minc, L.D. 1997. *Great Lakes coastal wetlands: An overview of abiotic factors affecting their distribution, form, and species composition*. Michigan Natural Features Inventory, Lansing, MI.

Minc, L.D., and Albert, D.A. 1998. *Great Lakes coastal wetlands: abiotic and floristic characterization.* Michigan Natural Features Inventory, Lansing, MI.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington. http://www.ijc.org/rel/agree/quality.html, last accessed March 15, 2005.

Wilcox, D.A., and Whillans, T.H. 1999. Techniques for restoration of disturbed coastal wetlands of the Great Lakes. *Wetlands* 19:835-857.

Urban Density

Indicator #7000

Assessment: Mixed, Trend not assessed
Data are not system wide

Purpose

- To assess the human population density in the Great Lakes basin, and to infer the degree of inefficient land use and urban sprawl for 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 who inhabit a city or town in relation to the geographic area of that city or town. Urban sprawl 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 (Neill *et al.* 2003). For this assessment, the data analyzed was based on Metropolitan Statistical Areas (MSAs) from the 2000 and 1990 U.S. Census and Census Metropolitan Areas (CMAs) from the 2001 and 1996 Canadian Census.

This indicator offers information on the presence, location, and predominance of human-built land cover and 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 10,000 but less than 50,000 populations. The urban densities 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.

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.

Fortunately, in the Great Lakes basin, as there has been an increase in population, there has also been an increase in the average densities of the CMAs and MSAs. In the United States the average density in MSAs increased from 177.5 people/km^2 in 1990 to 191.0 people/km^2 in 2000 and in Canada the average density in CMAs increased from 326.4 people/km^2 in 1996 to 352.1 people/km^2 in 2001. Although this increase in density indicates healthier growth patterns for our metropolitan areas, it does not imply that we have achieved our sustainable objectives. Within the CMAs and MSAs the population and density have been increasing. However, within the CMAs and MSAs the amount of land being developed is escalating at a greater rate than the population growth rate. Therefore, 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.

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. This indicates that a few areas seem to be improving their growth patterns, while many other areas need to advance to a more sustainable development pattern. 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 and these implications will continue to threaten the Great Lakes basin ecosystem unless this pattern is reversed.

Pressures

Sprawl is increasingly becoming a problem in rural and 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.

Acknowledgments

Author: Lindsay Silk, Environment Canada Intern, Downsview, ON; and

Ric Lopez, U.S. Environmental Protection Agency, Las Vegas, NV.

Sources

Bradof, K. GEM Center for Science and Environmental Outreach, Michigan Technological University, MI, and James G. Cantrill, Communication and Performance Studies, Northern Michigan University, MI.

GEM Center for Science and Environmental Outreach. 2000. *Baseline Sustainability Data for the Lake Superior Basin: Final Report to the Developing Sustainability Committee, Lake Superior Binational Program, November 2000*. Michigan Technological University, Houghton, MI. http://emmap.mtu.edu/gem/community/planning/lsb.html.

Gilbert, R., Bourne, L.S., and Gertler, M.S. 2001. *The State of GTA in 2000.* A report for the Greater Toronto Services Board. Metropole Consultants, Toronto, ON.

Loten, A. 2004. Sprawl plan our 'last chance:' Caplan. *Toronto Star,* July 29, 2004.

Neill, K.E., Bonser, S.P., and Pelley, J. 2003. *Sprawl Hurts Us All! A guide to the costs of sprawl development and how to create livable communities in Ontario*. Sierra Club of Canada, Toronto, ON.

Statistics Canada. 2001. Community Profiles and 1996 census subdivision area profiles. http://www12.statcan.ca/english/profil01/PlaceSearchForm1.cfm.

U.S. Census Bureau. American Fact Finder, Census 2000 Summary File 1 (SF 1) 100-Percent Data, Detailed Tables. http://factfinder.census.gov/servlet/DTGeoSearchByRelationshipServlet?_ts=109848346281.

Authors' Commentary

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.

Land Cover/Land Conversion

Indicator #7002

Assessment: Not Assessed

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) – see Figure 1. 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.

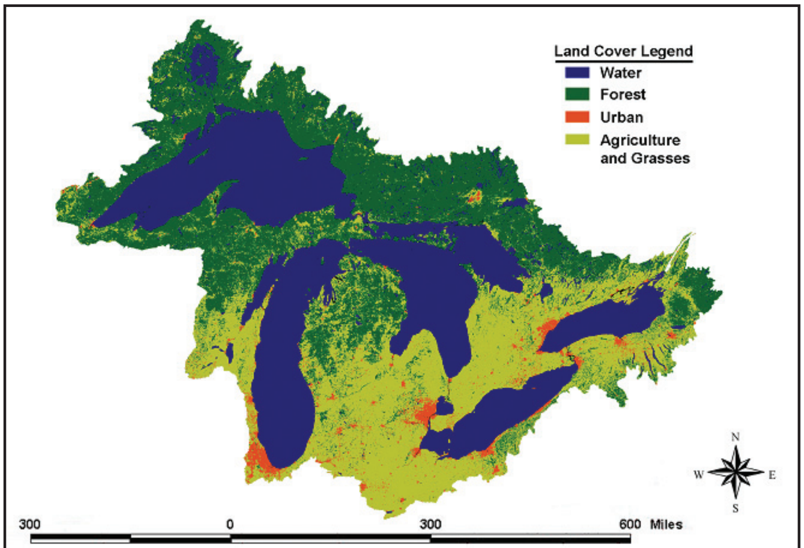


Figure 1. Binational land use data for 1990s.
Source: Zhang, Y. and B. Guindon. 2005. Landscape analysis of human impacts on forest fragmentation in the Great Lakes region. Can. J. Remote Sensing. 31(2):153-166

More recently, finer-resolution satellite imagery is allowing 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 26-category classification scheme (Figure 2) 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. 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:

Land Cover Type	Area in Hectares	Percentage of Total Land
Open Water	1,222,481*	4.20%
Low Intensity Residential	412,378	1.40%
High Intensity Residential	136,533	0.50%
TIGER Roads (1992)	1,675,899	5.80%
Commercial/Industrial	232,572	0.80%
Bare Rock/Sand/Clay	13,127	<0.1%
Quarries/Strip Mines/Gravel Pits	42,630	0.20%
Transitional	66,607	0.20%
Deciduous Forest	7,723,316	26.80%
Evergreen Forest	1,533,177	5.30%
Mixed Forest	1,790,038	6.20%
Shrubland	53,328	0.20%
Orchards/Vineyards/Other	216	<0.1%
Grasslands/Herbaceous	408,910	1.40%
Pasture/Hay	3,818,427	13.30%
Row Crops	6,801,486	23.60%
Small Grains	4,321	<0.1%
Urban/Recreational Grasses	102,940	0.40%
Emergent Herbaceous Wetlands	681,884	2.40%
Unconsolidated Shore	5,481	<0.1%
Lowland Grasses	139,226	0.50%
Lowland Scrub/Shrub	516,811	1.80%
Lowland Conifers	743,233	2.60%
Lowland Mixed Forest	678,830	2.40%
TOTAL	**28,803,849**	

* preliminary estimate

Table 1. Land Cover type, area, and percentage of total land for the U.S. Great Lakes basin. (*Preliminary estimate)
Source: Natural Resources Research Institute, University of Minnesota - Duluth

The remote-sensing data from satellite imagery needs to be validated with field sampling data. Satellite data can be difficult to interpret; thus there is often difficulty in distin guishing among various land use classes.

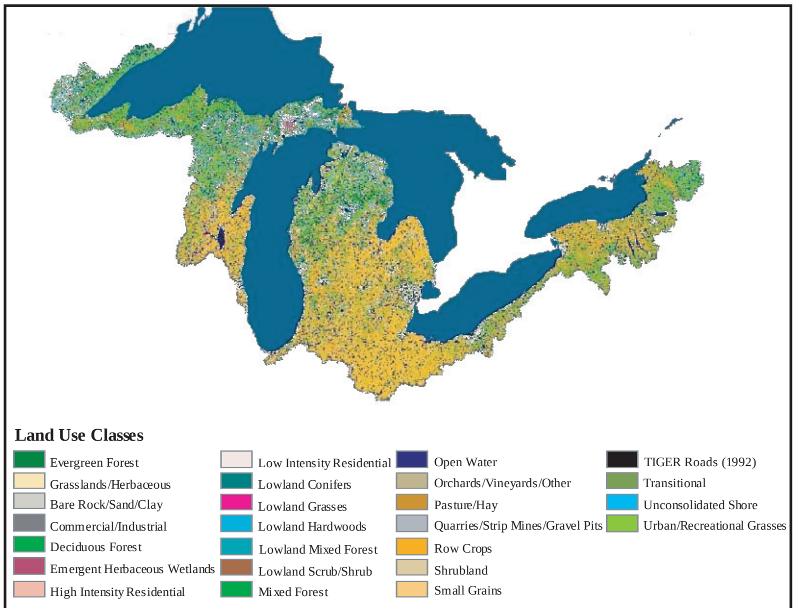


Figure 2. Land use in the U.S. Great Lakes basin.
Source: Natural Resources Research Institute, University of Minnesota - Duluth. Based on the National Land Cover Database (1992) of the U.S. Geological Survey (USGS) and other data sets

Forest inventories present a key source of field data on land use. The Ontario Ministry of Natural Resources (OMNR) relies on a combination of aerial photography and field sampling for its Forest Resources Inventory database. The following data for the Canadian Great Lakes basin are a mosaic of data collected between 1978 and 2001:

Land Cover Type	Area in Hectares	Percentage of Total Land
Productive Forest	13,045,401	60.20%
Open Muskeg	486,235	2.20%
Treed Muskeg	226,023	1.00%
Brush/Alder	201,954	1.40%
Grass/Meadow	644,473	3.00%
Developed Agricultural Land	3,124,074	14.40%
Rock	274,509	1.30%
Unclassified (mostly urban)	868,054	4.00%
Water	2,713,558	12.50%
TOTAL	**21,674,181**	

Table 2. Land cover type, area and percentage of total land in the Canadian Great Lakes basin.
Source: Ontario Ministry of Natural Resources (OMNR), Forest Resources Inventory database

The U.S. Department of Agriculture (USDA) Forest Service also has a field sampling protocol, the Forest Inventory and Analysis database. The following data is for the U.S. Great Lakes basin (Figure 3). In six of the eight Great Lakes states, data were collected in 2002; Michigan data is from 2001, while Ohio data is from 1991:

Land Cover Type	Area in Hectares	Percentage of Total Land
Forest	14,746,054	46.60%
Non-forest	14,981,127	47.30%
Non-census Water	206,576	0.70%
Census Water	1,724,577	5.50%
Denied Access	8,467	<0.1%
Hazardous	4,101	<0.1%
TOTAL	**31,670,902**	

Table 3. Forest and non-forest land cover type, area and percentage of total for the U.S. Great Lakes basin.
Source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis database

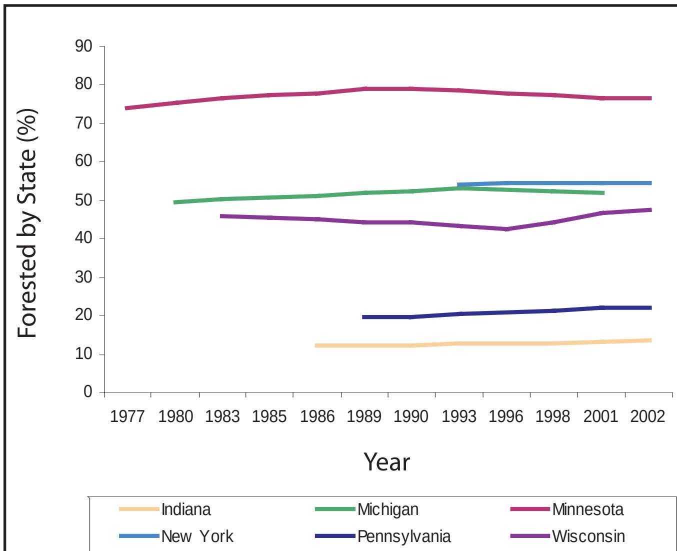


Figure 3. Percentage of land under forest cover in the U.S. Great Lakes basin, by state, 1977-2002. Includes only the portion of each state within the watershed.
Source: U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis database

USDA data from the past quarter-century are also available, enabling an analysis of land conversion in the U.S. Great Lakes basin over time. Due to the different reporting cycles in the eight states, a uniform baseline cannot be established for basin-wide analysis. However, a state-by-state analysis reveals that forest cover has generally been increasing across the basin in recent decades, while non-forest areas have cor respondingly decreased.

It should be noted that the data sets discussed in this report were developed independently under different protocols. Making direct comparisons among them will require closer coordination of survey methods and data definitions.

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.

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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.

Authors' Commentary
Land classification data must be standardized. The resolution should be fine enough to be useful at lake watershed and sub-watershed levels.

Brownfields Redevelopment

Indicator #7006

This indicator report is from 2003.

Assessment: Mixed, Improving
Data from multiple sources are not consistent.

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
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. These 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.

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. Most states track the amount of funding assistance provided as well as the number of sites that have been redeveloped. 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. Adding up state and provincial information to come up with a brownfields figure that represents the collective eight states and two provinces is challenging at best. 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 and Quebec indicate that, as of August, 2002, a total of 12,992 hectares (32,103 acres) have been remediated in these states and provinces alone, and approximately 1,862 hectares (4,600 acres) were remediated between 2000-2002. Available data from eight Great Lakes states and Quebec indicates that more than 24,000 brownfields sites have participated in brownfields clean-up programs since the mid-1990s, although the degree of "remediation" varies considerably.

Figure 1. Redeveloped brownfield site, Erie Front Street Complex, Pennsylvania.
Source: Pennsylvania Department of Environmental Quality

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. 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 ongoing 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 conversion, data should be collected that will enable an evaluation of each of these activities.

Acknowledgments

Author: Victoria Pebbles, Senior Project Manager, Transportation and Sustainable Development, Great Lakes Commission, Ann Arbor, MI, vpebbles@glc.org, www.glc.org. With assistance from Becky Lameka and Kevin Yam, Great Lakes Commission, Ann Arbor, MI.

Sources

Selected Annual Reports of state cleanup programs.

Personal communication with Great Lakes State Brownfield/Voluntary Cleanup Program Managers.

Authors’ Commentary

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).

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-

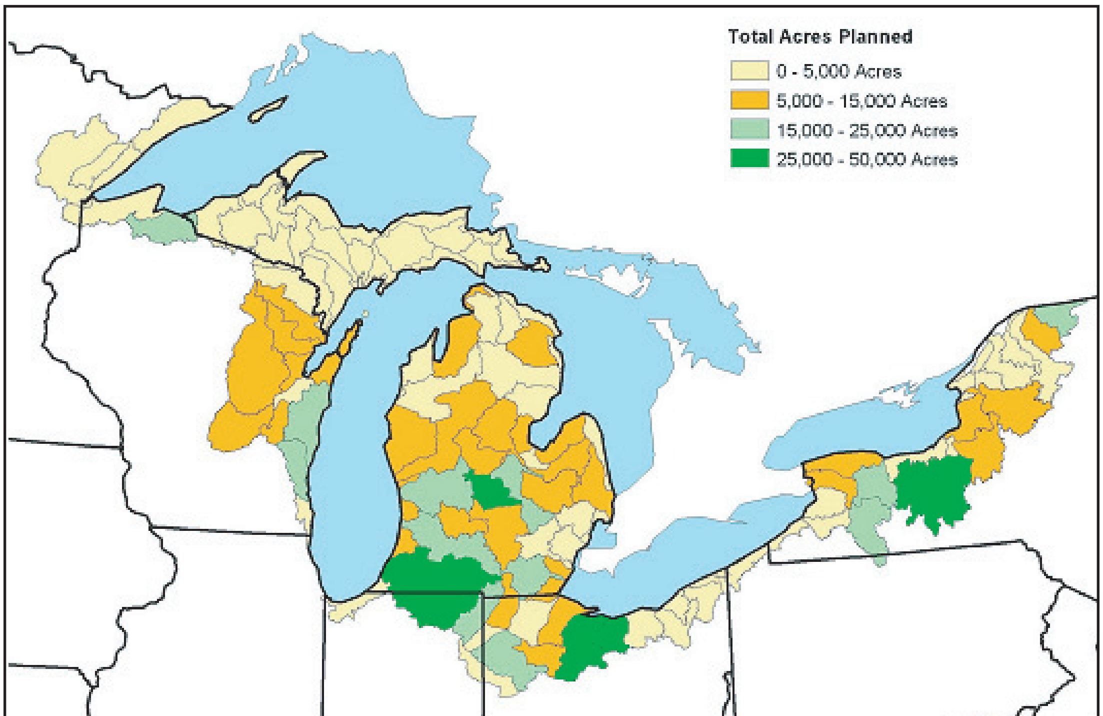

Figure 1. Acres of cropland in U.S portion of the basin covered under a conservation plan, 2003.
Source: Natural Resource Conservation Service, U.S. Department of Agriculture

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.

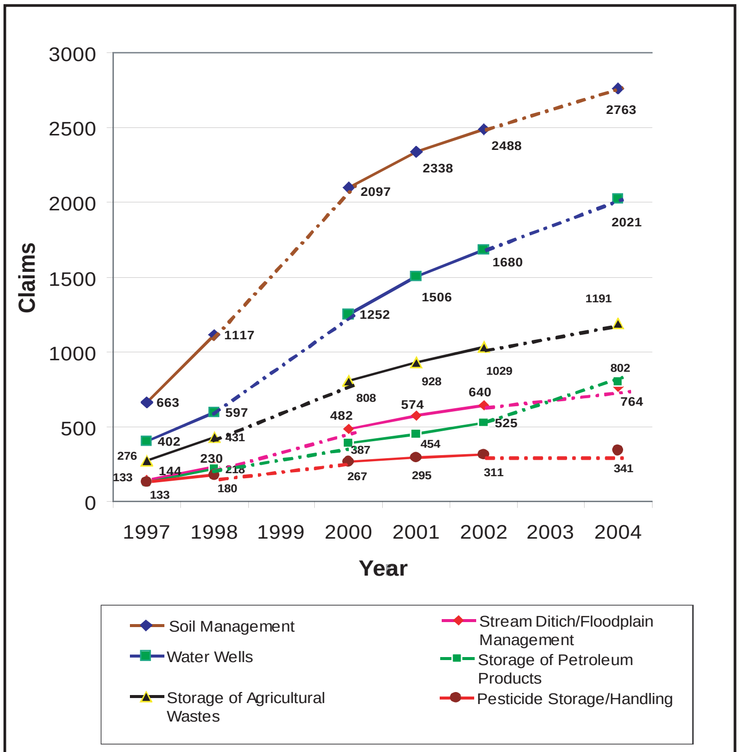

Figure 2. EFP: Cumulative Number of Incentive Claims by Worksheet (Issues). Six of 23 worksheets/issues are represented here - these six worksheets represent 70% of all EFP incentive claims. Three worksheets (Soil, Water and Storage of Agricultural Wastes) represent significant environmental actions 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.

Acknowledgments

Authors: Peter Roberts, Water Management Specialist, Ontario

Ministry of Agriculture and Food (OMAF), Guelph, Ontario
Canada, peter.roberts@omaf.gov.on.ca;
Ruth Shaffer, United States Department of Agriculture (USDA),
Natural Resource Conservation Service (NRCS),
ruth.shaffer@mi.usda.gov; and
Roger Nanney, United States Department of Agriculture
(USDA), Natural Resources Conservation Service (NRCS),
roger.nanney@in.usda.gov.

Sources

Ontario Soil and Crop Improvement Association. 2004.
Environmental Farm Plan Database.

Economic Prosperity

Indicator #7043

This indicator report is from 2003.

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.

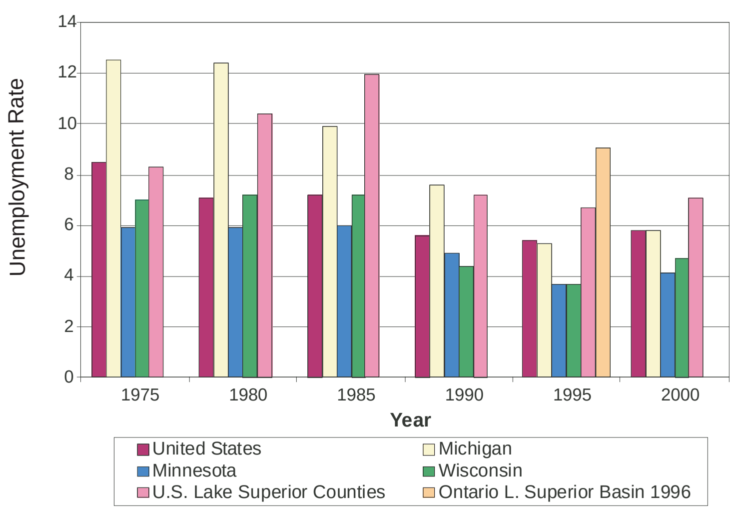

Figure 1. Unemployment rate in the U.S. (national), Michigan, Wisconsin, and the U.S. portion and Ontario portion of the Lake Superior basin, 1975-2000.
Source: U.S. Census Bureau and Statistics Canada

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.

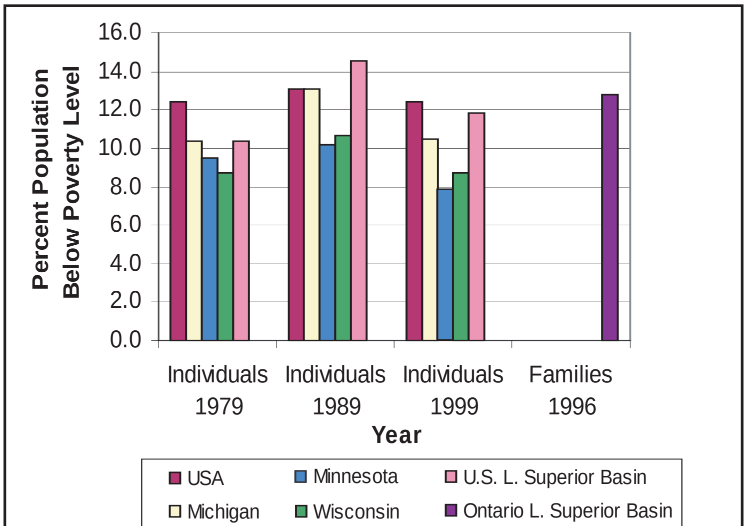

Figure 2. Individuals below poverty level in the U.S. (national), Michigan, Wisconsin, and the U.S. Great Lakes basin counties, 1979-1999, and families below poverty level in Ontario Great Lakes basin subdivisions, 1996.
Source: U.S. Census Bureau and Statistics Canada

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.

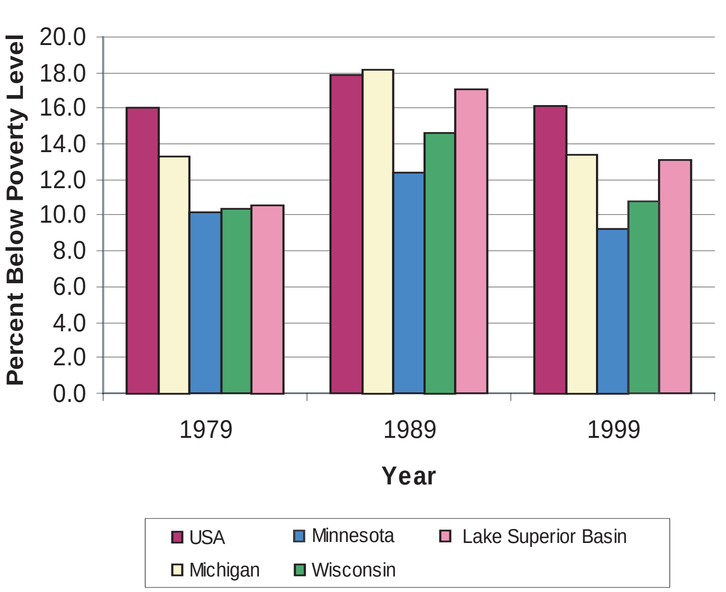

Figure 3. Children under age 18 below the poverty level, 1979-1999, U.S. (national), Michigan, Minnesota, Wisconsin and U.S. portion of the Lake Superior basin.
Source: U.S. Census Bureau

Sources
GEM Center for Science and Environmental Outreach. 2000. *Baseline Sustainability Data for the Lake Superior Basin: Final Report to the Developing Sustainability Committee, Lake Superior Binational Program, November 2000*. Unpublished report, Michigan Technological University, Houghton, MI. http://emmap.mtu.edu/gem/community/planning/lsb.html.

Statistics Canada. 1996. *Beyond 20/20 Census Subdivision Area Profiles for the Ontario Lake Superior Basin*.

U.S. Census Bureau. 2002. *Population by poverty status in 1999 for counties: 2000*. http://www.census.gov/hhes/poverty/2000census/poppvstat00.html.

U.S. Census Bureau. *State & County Quick Facts 2000*. Table DP-3. Profile of Selected Economic Characteristics. http://censtats.census.gov/data/MI/ 04026.pdf#page=3.

U.S. Census Bureau. *USA Counties 1998 CD-ROM* (includes unemployment data from Bureau of Labor Statistics).

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.

Ground Surface Hardening

Indicator #7054

Note: This is a progress report towards implementing this indicator.

Assessment: Not Assessed

The available information are incomplete, or outdated.

Purpose

- To indicate the degree to which development is affecting natural water drainage and percolation processes, thus causing erosion and other effects through high water levels during storm events and reducing natural groundwater regeneration processes; and
- To measure the impacts of land development on aquatic systems.

Ecosystem Objectives

A goal for the ecosystem is sustainable development. This would entail minimizing the quantities of impervious surface by using alternatives for replacement and future development.

State of the Ecosystem

Background

Ground surface hardening, or imperviousness, is the sum of area of roads, parking lots, sidewalks, roof tops and other impermeable surfaces of the urban landscape is a useful indicator with which to measure the impacts of land development on aquatic ecosystems (Center for Watershed Protection 1994).

Information on ground surface hardening in the Great Lakes basin is currently in the development stage. Different organizations are working towards developing effective systems of analyzing the status of this indicator. The use of technology such as Landsat imagery and Geographic Information Systems (GIS) applications are being utilized in efforts to evaluate the current state. The instruments on the Landsat satellites have acquired millions of images. These images form a unique resource for applications in agriculture, geology, forestry, regional planning, education, mapping, and global change research. This type of information will help illustrate the land use qualities of the Great Lakes basin.

In attempts to obtain information for this indicator many avenues were explored. Within Ontario, the Ontario Ministry of the Environment, Conservation Authorities and municipalities of different sizes were contacted for a random survey to see what information was available. Each organization had very little available information on impervious surfaces.

The Ontario Ministry of Natural Resources is in the process of implementing a project called Southern Ontario Land Resource Information System (SOLRIS). SOLRIS is a mapping program designed to accurately measure the nature and extent of Southern Ontario's natural resources and will be used to track changes to the natural, rural and urban landscape (Mussakowski 2004). SOLRIS integrates existing base resource information and advanced GIS and remote sensing techniques to derive a comprehensive land cover database. SOLRIS is attempting to complete the assembly of all layers into comprehensive land cover/use mapping by 2006 and will continue to upgrade on 5 or 10 year intervals.

Recently, Christopher Elvidge of the U.S. National Oceanic and Atmospheric Administration's National Geophysical Data Center in Boulder, Colorado, along with colleagues from several universities and agencies produced the first national map and inventory of impervious surface areas (ISA) in the United States. The new map is important, because impervious surface areas affect the environment. The qualities of impervious materials that make them ideal for construction also create urban heat islands by reducing heat transfer from the Earth's surface to the atmosphere. The replacement of heavily vegetated areas by ISA also reduces the sequestration of carbon from the atmosphere (Elvidge 2004).

Pressures

Growth patterns in North America can be generalized, with few exceptions, as urban sprawl. As our cities continue to grow outwards there is a growing dependency on personal transportation. This creates a demand for more roads, parking lots and driveways. Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other sources. Imperviousness represents the imprint of land development on the landscape (Center for Watershed Protection 1994).

A long-term, adverse impact to water quality could occur as a result of the continued and likely increase of nonpoint-source pollution discharge to stormwater runoff from roads, parking lots, and other impervious surfaces introduced into the area to accommodate visitor use. If parking lots, roads, and other impervious surfaces are established where none currently exist, then vehicle-related pollutants and refuse may accumulate. This impact could be mitigated to a negligible level through the use of permeable surfaces and vegetated or natural filters or traps for filtering stormwater runoff (National Park Service 2001).

Management Implications

Ground surface hardening is an important indicator in the Great Lakes basin that needs to be explored further. The information available for this indicator is incomplete, or outdated. With current technological advancements there are emerging methods of monitoring impervious surfaces, and hopefully within 5 years the data required for this report will be complete. Ground surface hardening has many detrimental effects on the environment; thus, it is essential to monitor and seek alternatives.

Acknowledgments
Author: Lindsay Silk, Environment Canada, Downsview, Ontario.

Sources

Center for Watershed Protection. 1994. The importance of imperviousness. *Watershed Protection Techniques* 1(3):100-111.

Elvidge, C. 2004. National Oceanic and Atmospheric Administration.

Mussakowski, R. 2004. Ontario Ministry of Natural Resources.

National Park Service. 2001. Merced Wild and Scenic River: Comprehensive Management Plan. http://www.cwp.org/SPSP/TOC.htm.

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.

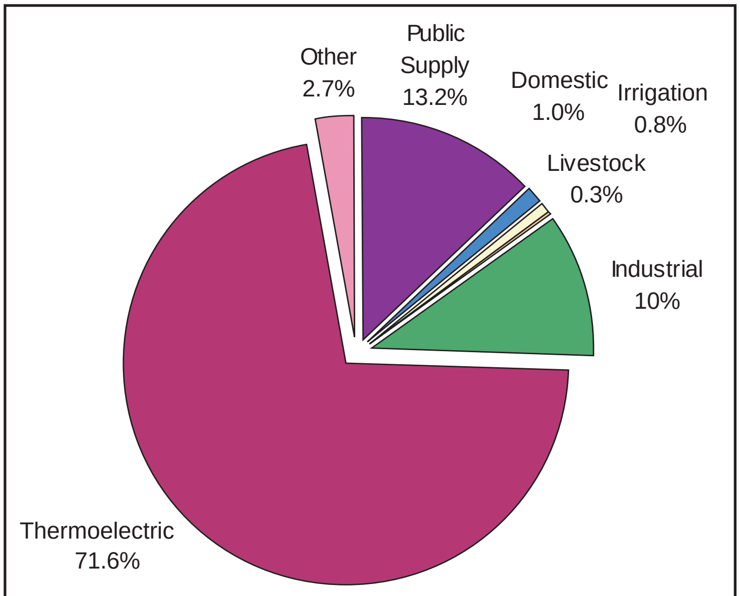

Figure 1. Water Withdrawals in the Great Lakes basin, by category as percentage of total, 2000.
Source: Great Lakes Commission, 2004

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).

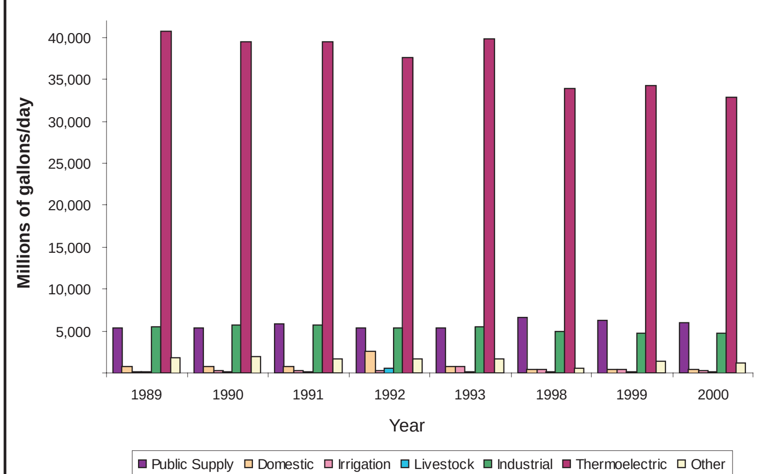

Figure 2. Great Lakes basin water withdrawals by category, 1989-1993 and 1998-2000.
Source: Great Lakes Commission, 1991-2004

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

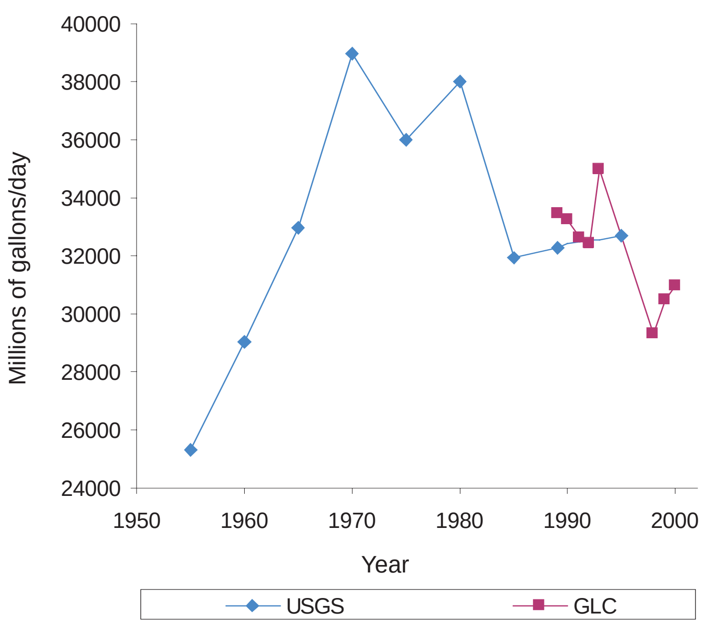

Figure 3. U.S. basin water withdrawals, 1950-2000. Source: U.S. Geological Survey, 1950-2000. Great Lakes Commission (GLC).

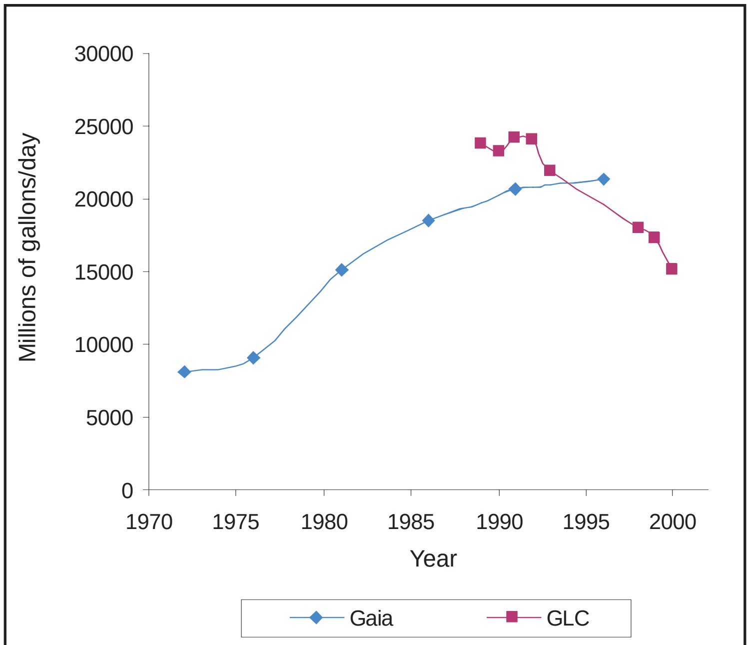

Figure 4. Canadian basin water withdrawals, 1972-2000. Source: Gaia Economic Research Associates, 1999 (based on data from Environment Canada and Statistics Canada). Great Lakes Commission (GLC).

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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Sources

Burke, D., Leigh, L., and Sexton, V. 2001. *Municipal water pricing, 1991-1999.* Environment Canada, Environmental Economics Branch.

Environment Canada. 2004. Great Lakes-St. Lawrence Regulation Office.

Gaia Economic Research Associates. 1999. *Water demands in the Canadian section of the Great Lakes basin 1972-2021*.

Great Lakes Commission (GLC). 2004. *Great Lakes regional water use database*. http://www.glc.org/wateruse/database/search.html.

Great Lakes Commission (GLC). 2003. *Toward a water resources management decision support system for the Great Lakes-St. Lawrence River basin: status of data and information on water resources, water use, and related ecological impacts*. Chapter.3, pp.58-62. http://www.glc.org/wateruse/wrmdss/finalreport.html.

Harris, J., and Tate, D. 1999. *Water demands in the Canadian section of the Great Lakes basin, 1972-2021.* Gaia Economic Research Associates (GERA) Report, Ottawa, ON.

Mills, E.L., Leach, J.H., Carlton, J.T., and Secor, C.L. 1993.

Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. *J. Great Lakes Res*. 19(1):1-54.
Renzetti, S. 1999. Municipal water supply and sewage treatment: costs, prices and distortions. *The Canadian Journal of Economics.* 32(3):688-704.

U.S. Geological Survey (USGS). 1950-2000. E*stimated Water Use in the United States: circulars published at 5-year intervals since 1950.* http://water.usgs.gov/watuse/.

U.S. Geological Survey (USGS). 1985. *Estimated use of water in the United States in 1985*. 68pp.

Visocky, A.P. 1997. Water-level trends and pumpage in the deep bedrock aquifers in the Chicago region, 1991-1995. Illinois State Water Survey Circular 182. Cited in International Joint Commission. 2000. *Protection of the waters of the Great Lakes: final report to the governments of Canada and the United States*. Chapter.6, pp 20-26. http://www.ijc.org/php/publications/html/finalreport.html.

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

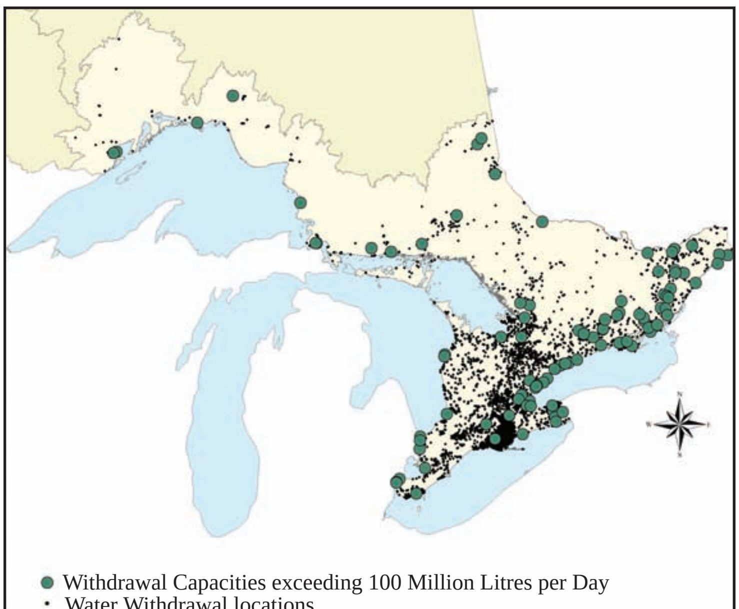

Figure 5. Permitted water withdrawal capacities in the Ontario portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources

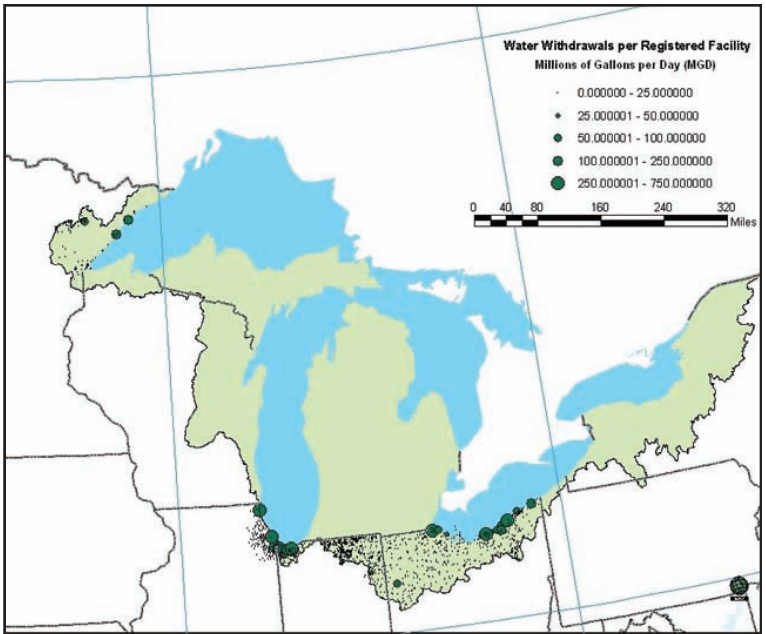

Figure 6. Map of Reported Water Withdrawals at Permitted or Registered Locations in Minnesota, Illinois, Indiana and Ohio. Source: IL Department of Natural Resources, MN Department of Natural Resources, OH Department of Natural Resources, IN Department of Natural Resources

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.

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

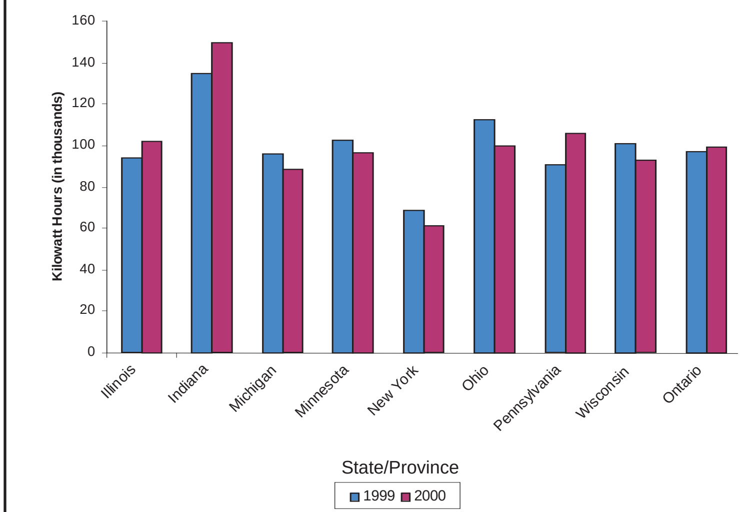

Figure 1. Total energy consumption per capita 1999-2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

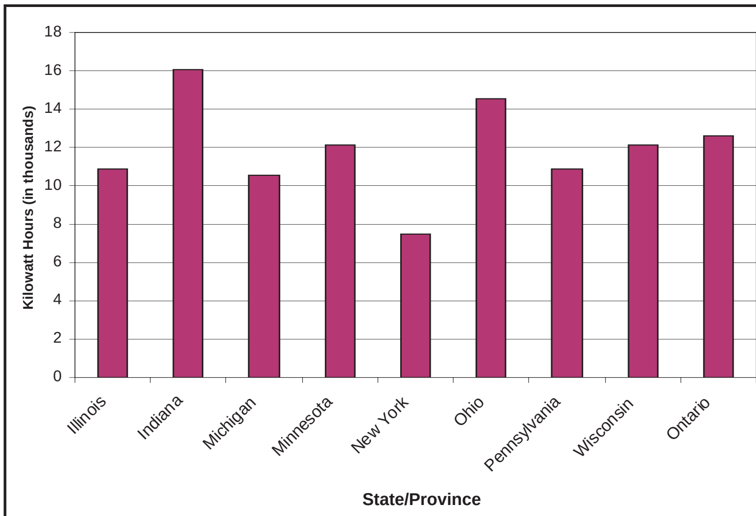

Figure 2. Electric energy consumption per capita 2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

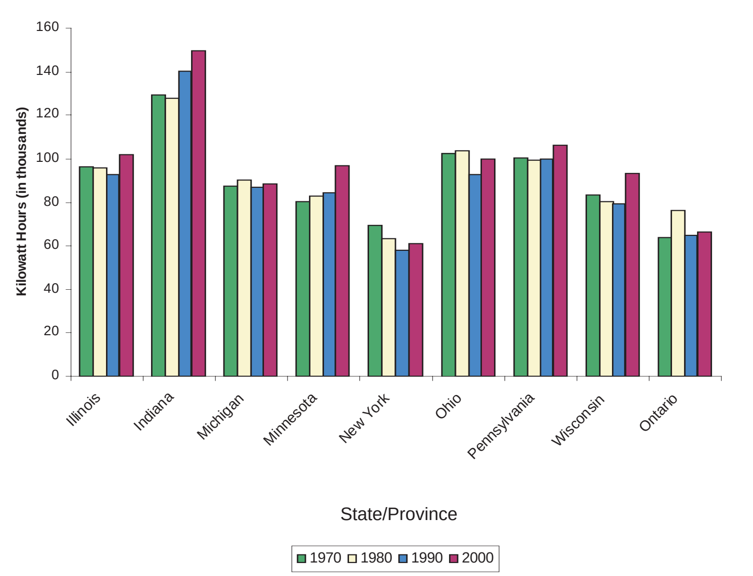

Figure 3. Total per capita energy consumption 1970-2000.1 MWh = 1000 kWh. Other energy sources include geothermal, wind, photovoltaic and solar energy. The Ontario data do not include the electricity generation sector due to an absence of data for this sector until 1978.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

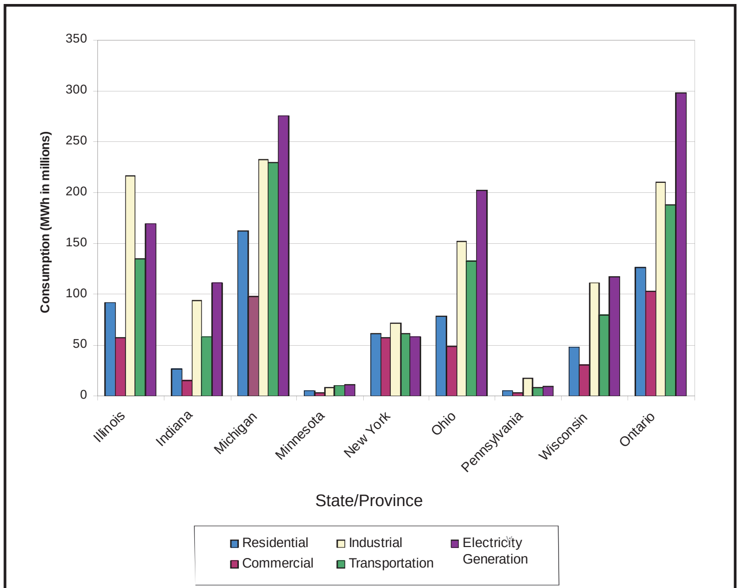

Figure 4. Secondary energy consumption within the Great Lakes basin by sector. Note: all data are from 2000, although 2002 data from Ontario are discussed in the report.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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.

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

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.

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

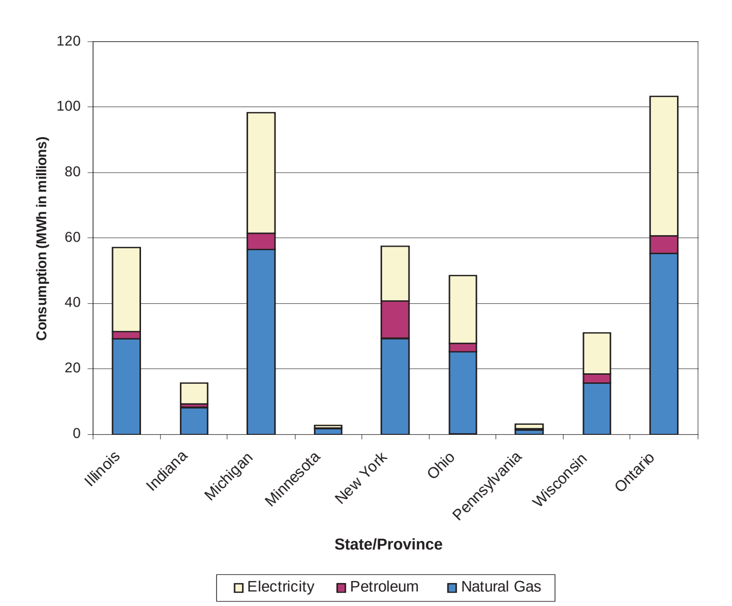

Figure 5. Commercial sector energy consumption by source, 2000. Wood and coal were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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).

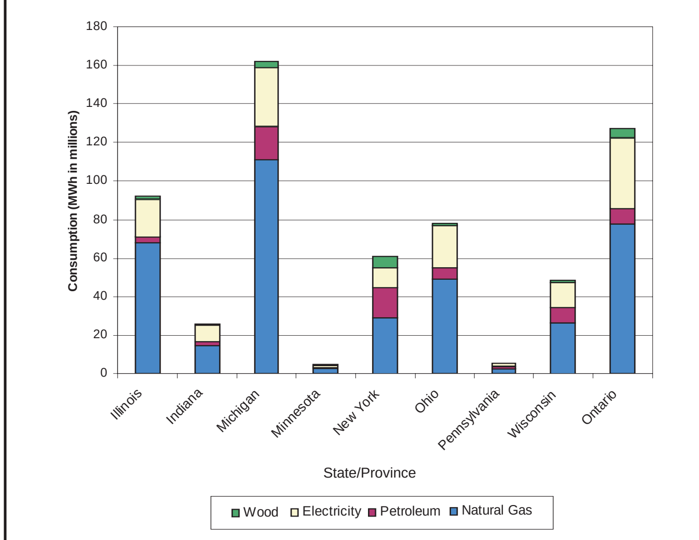

Figure 6. Residential sector energy consumption by source, 2000. Coal, geothermal, and solar energy were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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).

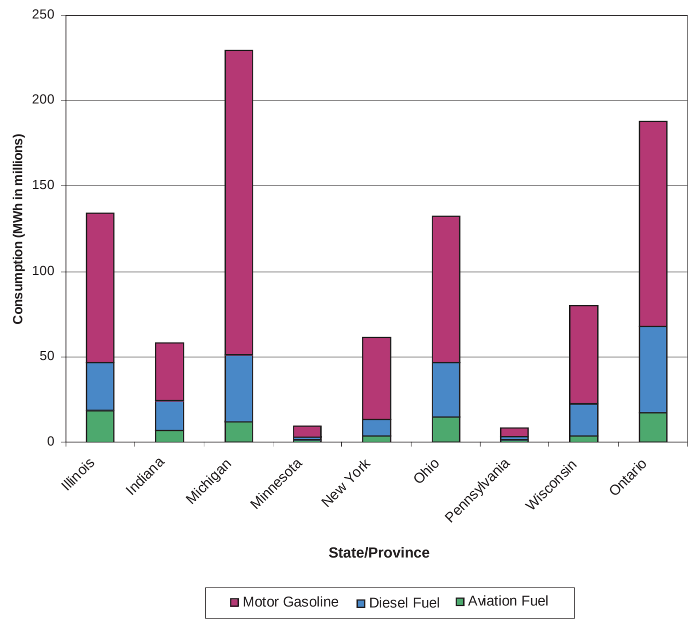

Figure 7. Transportation sector energy consumption by source, 2000. Natural gas and electricity were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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.

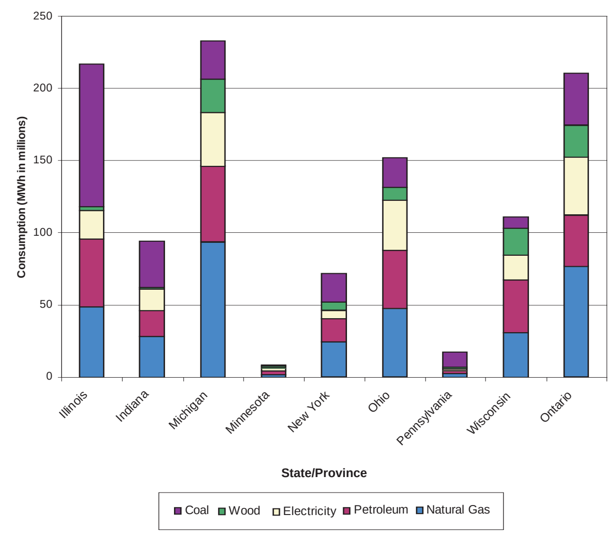

Figure 8. Industrial sector energy consumption by source, 2000. Hydroelectric power was a minor source in this sector. U.S. data for wood include wood waste.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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

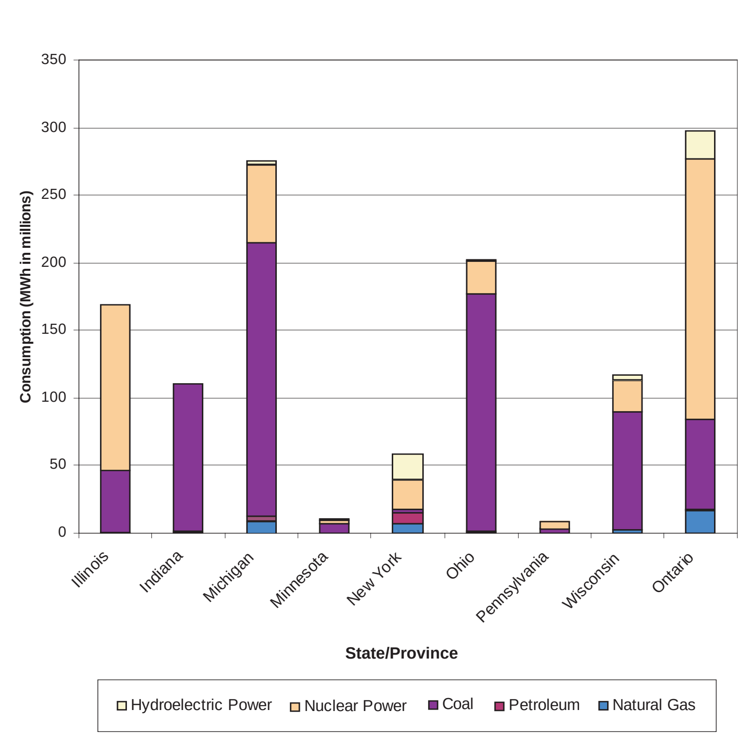

Figure 9. Electricity generation sector energy consumption by source, 2000. Wood and wood waste were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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.

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Sources
Canada and U.S. Country Analysis Briefs. 2005. *Energy Information Administration*. http://www.eia.doe.gov/emeu/cabs/canada.html, last accessed October 4, 2005.

Energy Efficiency and Renewable Energy (EERE) Network News. 2004. *DOE Awards $94.8 Million to Weatherize Homes in 20 States*. U.S. Department of Energy. http://www.eere.energy.gov/news/news_detail.cfm/news_id=7438, last accessed October 4, 2005.

Environment Canada. 2003. *Environmental Signals, Canada's National Environmental Indicator Series 2003, Energy Consumption*. pp 56-59. http://www.ec.gc.ca/soer-ree.

Garman, D.K. 2004. *Administration's views on the role that renewable energy technologies can play in sustainable electricity generation.* United States Senate, Testimony before the Committee on Energy and Natural Resources. http://www.eere.energy.gov/office_eere/congressional_test_042704.html.

National Energy Policy Development Group (NEPDG). 2001. *Report of the National Energy Policy Development Group*. http://energy.gov/engine/content.do?BT_CODE=AD_AP.

Natural Resources Canada. 2002. *Energy Efficiency Trends in Canada 1990-2000.* http://oee.nrcan.gc.ca/neud/dpa/home.cfm.

Natural Resources Canada. *Comprehensive Energy Use Database*. http://oee.nrcan.gc.ca/neud/dpa/comprehensive_tables/.

Statistics Canada. 2000. *Human Activity and the Environment 2000*. [CDRom].

U.S. Census Bureau and Texas State Data Center. 2000. *U.S. 2000 decennial census data.* Department of Rural Sociology, Texas A&M University. http://www.census.gov/dmd/www/resapport/states/indiana.pdf and http://www.txsdc.tamu.edu/txdata/apport/hist_a.php.

U.S. Energy Information Administration (EIA). 2004. *State energy data 2000 consumption tables.* http://www.eia.doe.gov.

U.S. Environmental Protection Agency (USEPA). 2003. *ENERGY STAR - The power to protect the environment through energy efficiency.* http://www.energystar.gov/ia/partners/downloads/energy_star_report_aug_2003.pdf.

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.

Ice Duration on the Great Lakes

Indicator #4858

This indicator report is from 2003.

Assessment: Mixed, 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).

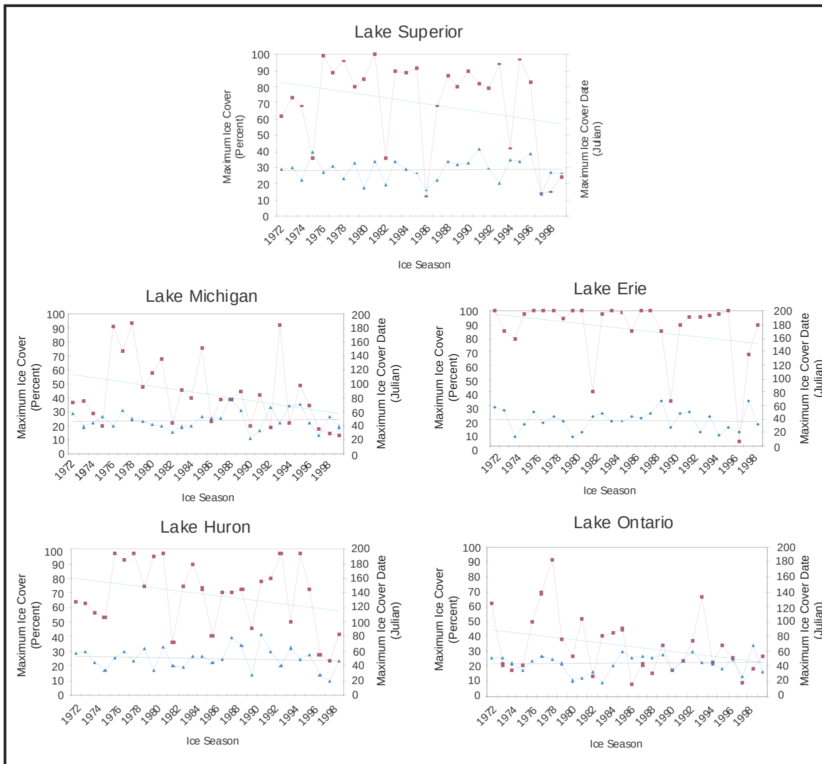

Figure 1. Trends of maximum ice cover and the corresponding date on the Great Lakes, 1972-2000. The red line represents the percentage of maximum ice cover and the blue line represents the date of maximum ice cover. Source: National Oceanic and Atmospheric Administration

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).

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.

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

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. The more data that are received will increase the statistical significance of the results.

Acknowledgments

Author: Gregg Ferris, Environment Canada Intern, Downsview, ON.
All data analyzed and charts created by the author.

Sources

Magnuson, J.J., Robertson, D.M., Benson, B.J., Wynne, R.H., Livingston, D.M., Arai, T., Assel, R.A., Barry, R.G., Carad, V., Kuusisto, E., Granin, N.G., Prowse, T.D., Stewart, K.M., and Vuglinski, V.S. 2000. Historical trends in lake and river ice covering the Northern Hemisphere. *Science* 289(Sept. 8):1743-1746.

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

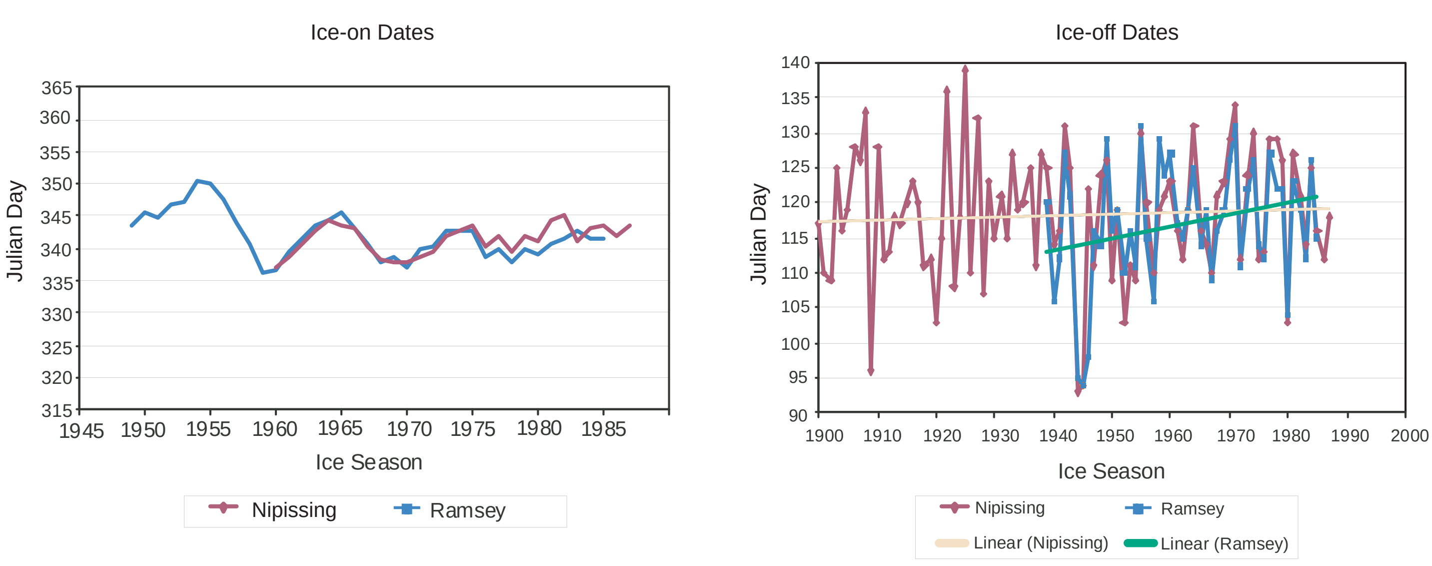

Figure 2. Ice-on and ice-off dates for Lake Nipissing (red line) and Lake Ramsey (blue line). Data were smoothed using a 5-year moving average.
Source: Climate and Atmospheric Research and Environment Canada

Canada-Ontario Region.

Authors' Commentary
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. The most substantial of these is the Kyoto Protocol, which looks at decreasing the emissions of greenhouse gases by 2008, with a large amount of attention on decreasing carbon dioxide. Countries that have not agreed to adhere to this protocol are taking other measures to reduce their emissions.

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.

Effect of Water Level Fluctuations

Indicator #4861

This indicator report is from 2003.

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 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.

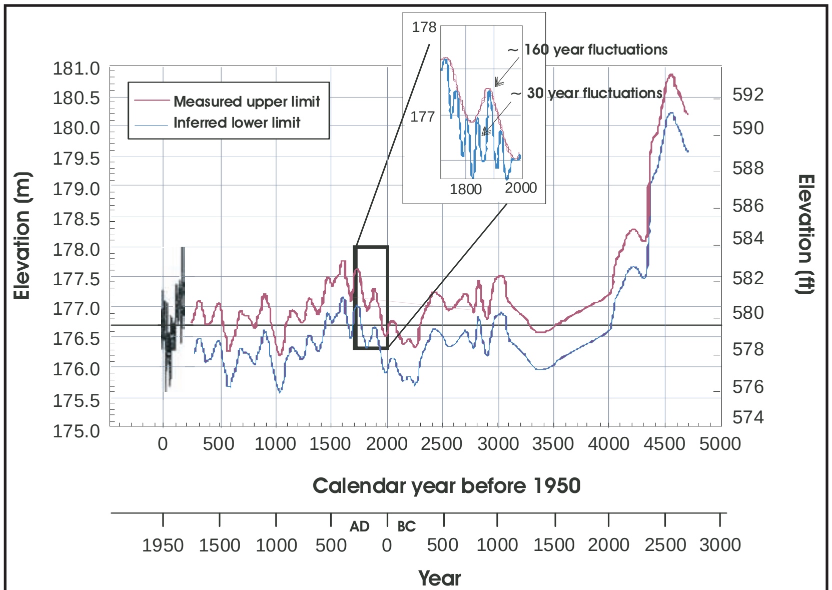

Figure 1. Sediment investigations on the Lake Michigan-Huron system indicates quasi-periodic lake level fluctuations.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

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

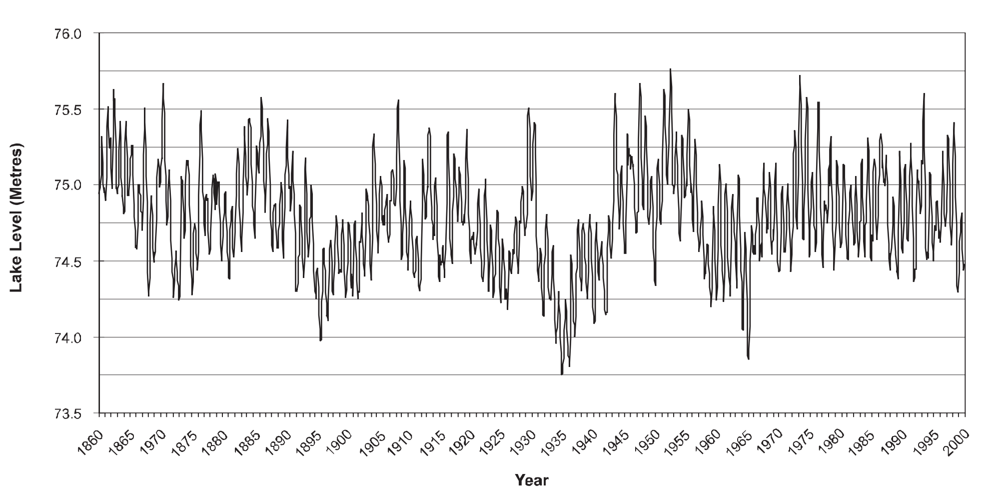

Figure 2. Actual water levels for Lake Ontario. IGLD-International Great Lakes Datum. Zero for IGLD is Rimouski, Quebec, at the mouth of the St. Lawrence River. Water level elevations in the Great Lakes/St. Lawrence River system are measured above water level at this site.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

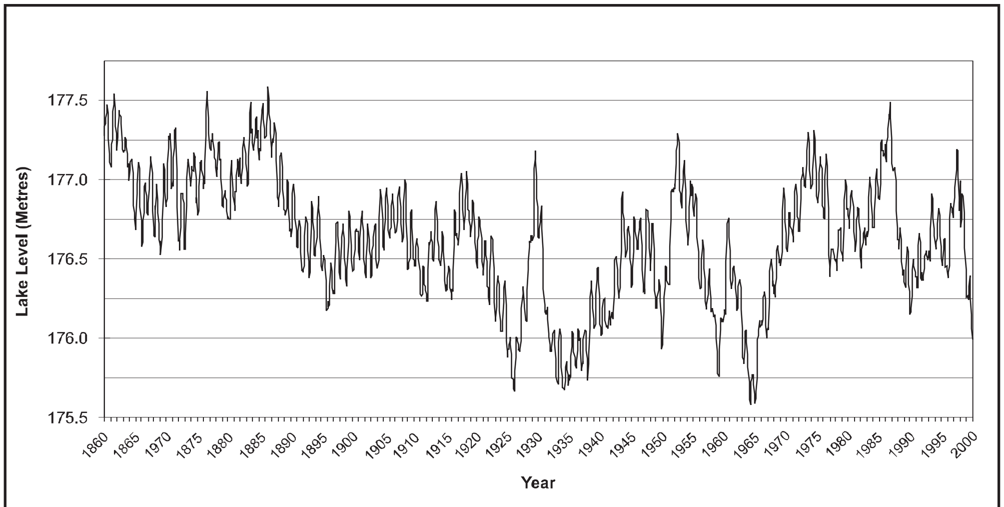

Figure 3. Actual water levels for Lakes Huron and Michigan. IGLD-International Great Lakes Datum. Zero for IGLD is Rimouski, Quebec, at the mouth of the St. Lawrence River. Water level elevations in the Great Lakes/St. Lawrence River system are measured above water level at this site.
Source: National Oceanic and Atmospheric Administration, 1992 (and updates)

variation, the wetland zone would be much narrower and less diverse. Even very short-term fluctuations resulting from 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).

Sources

Baedke, S.J., and Thompson, T.A. 2000. A 4,700-year record of lake level and isostasy for Lake Michigan. *J. Great Lakes Res.* 26(4):416-426.

International Joint Commission. Great Lakes Regional Office, Windsor, ON and Detroit, MI.

International Lake Ontario-St. Lawrence River Study Board, Technical Working Group on Environment/Wetlands. http://www.ijc.org.

Maynard, L., and Wilcox, D. 1997. *Coastal wetlands of the Great Lakes*. State of the Lakes Ecosystem Conference 1996 Background Paper. Environment Canada and U.S. Environmental Protection Agency.

National Oceanic and Atmospheric Administration (NOAA). 1992 (and updates). *Great Lakes water levels, 1860-1990.* National Ocean Service, Rockville, MD.

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.

Coastal Wetland Plant Community Health

Indicator #4862

Assessment: Mixed, Undetermined

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).

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. 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

Sources

Albert, D.A., and Minc, L.D. 2001. Abiotic and floristic characterization of Laurentian Great Lakes' coastal wetlands. Stuttgart, Germany. *Verh. Internat. Verein. Limnol.* 27:3413-3419.

Albert, D.A., Wilcox, D.A., Ingram, J.W., and Thompson, T.A. In Press. Hydrogeomorphic Classification for Great Lakes Coastal Wetlands. *J. Great Lakes Res.*

Environment Canada and Central Lake Ontario Conservation Authority. 2004. *Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report.* Environment Canada, Downsview, ON: ECB-OR.

Herdendorf, C.E. 1988. *Classification of geological features in Great Lakes nearshore and coastal areas.* Protecting Great Lakes Nearshore and Coastal Diversity Project. International Joint Commission and The Nature Conservancy, Windsor, ON.

Herdendorf, C.E., Hakanson, L., Jude, D.J., and Sly, P.G. 1992. A review of the physical and chemical components of the Great Lakes: a basis for classification and inventory of aquatic habitats. In *The development of an aquatic habitat classification system for lakes*., eds. W.-D. N. Busch and P. G. Sly, pp. 109-160. Ann Arbor, MI: CRC Press.

Herdendorf, C.E., Hartley, S.M., and Barnes, M.D. (eds.). 1981a. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 1: Overview*. U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS- 81/02-v1.

Jaworski, E., Raphael, C.N., Mansfield, P.J., and Williamson, B.B. 1979. *Impact of Great Lakes water level fluctuations on coastal wetlands.* U.S. Department of Interior, Office of Water Resources and Technology, Contract Report 14-0001-7163, from Institute of Water Research, Michigan State University, East Lansing, MI, 351pp.

Keough J.R., Thompson, T.A., Guntenspergen, G.R., and Wilcox, D.A. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands* 19:821-834.

Minc, L.D. 1997. *Great Lakes coastal wetlands: An overview of abiotic factors affecting their distribution, form, and species composition*. Michigan Natural Features Inventory, Lansing, MI.

Minc, L.D., and Albert, D.A. 1998. *Great Lakes coastal wetlands: abiotic and floristic characterization.* Michigan Natural Features Inventory, Lansing, MI.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington. http://www.ijc.org/rel/agree/quality.html, last accessed March 15, 2005.

Wilcox, D.A., and Whillans, T.H. 1999. Techniques for restoration of disturbed coastal wetlands of the Great Lakes. *Wetlands* 19:835-857.

Urban Density

Indicator #7000

Assessment: Mixed, Trend not assessed

Data are not system wide

Purpose

- To assess the human population density in the Great Lakes basin, and to infer the degree of inefficient land use and urban sprawl for 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 who inhabit a city or town in relation to the geographic area of that city or town. Urban sprawl 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 (Neill *et al.* 2003). For this assessment, the data analyzed was based on Metropolitan Statistical Areas (MSAs) from the 2000 and 1990 U.S. Census and Census Metropolitan Areas (CMAs) from the 2001 and 1996 Canadian Census.

This indicator offers information on the presence, location, and predominance of human-built land cover and 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 10,000 but less than 50,000 populations. The urban densities 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.

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.

Fortunately, in the Great Lakes basin, as there has been an increase in population, there has also been an increase in the average densities of the CMAs and MSAs. In the United States the average density in MSAs increased from 177.5 people/km^2 in 1990 to 191.0 people/km^2 in 2000 and in Canada the average density in CMAs increased from 326.4 people/km^2 in 1996 to 352.1 people/km^2 in 2001. Although this increase in density indicates healthier growth patterns for our metropolitan areas, it does not imply that we have achieved our sustainable objectives. Within the CMAs and MSAs the population and density have been increasing. However, within the CMAs and MSAs the amount of land being developed is escalating at a greater rate than the population growth rate. Therefore, 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.

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. This indicates that a few areas seem to be improving their growth patterns, while many other areas need to advance to a more sustainable development pattern. 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 and these implications will continue to threaten the Great Lakes basin ecosystem unless this pattern is reversed.

Pressures

Sprawl is increasingly becoming a problem in rural and 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.

Acknowledgments

Author: Lindsay Silk, Environment Canada Intern, Downsview, ON; and
Ric Lopez, U.S. Environmental Protection Agency, Las Vegas, NV.

Sources

Bradof, K. GEM Center for Science and Environmental Outreach, Michigan Technological University, MI, and James G. Cantrill, Communication and Performance Studies, Northern Michigan University, MI.

GEM Center for Science and Environmental Outreach. 2000. *Baseline Sustainability Data for the Lake Superior Basin: Final Report to the Developing Sustainability Committee, Lake Superior Binational Program, November 2000*. Michigan Technological University, Houghton, MI. http://emmap.mtu.edu/gem/community/planning/lsb.html.

Gilbert, R., Bourne, L.S., and Gertler, M.S. 2001. *The State of GTA in 2000*. A report for the Greater Toronto Services Board. Metropole Consultants, Toronto, ON.

Loten, A. 2004. Sprawl plan our 'last chance:' Caplan. *Toronto Star,* July 29, 2004.

Neill, K.E., Bonser, S.P., and Pelley, J. 2003. *Sprawl Hurts Us All! A guide to the costs of sprawl development and how to create livable communities in Ontario*. Sierra Club of Canada, Toronto, ON.

Statistics Canada. 2001. Community Profiles and 1996 census subdivision area profiles. http://www12.statcan.ca/english/profil01/PlaceSearchForm1.cfm.

U.S. Census Bureau. American Fact Finder, Census 2000 Summary File 1 (SF 1) 100-Percent Data, Detailed Tables. http://factfinder.census.gov/servlet/DTGeoSearchByRelationshipServlet?_ts=109848346281.

Authors' Commentary

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.

Land Cover/Land Conversion

Indicator #7002

Assessment: Not Assessed

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) – see Figure 1. 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.

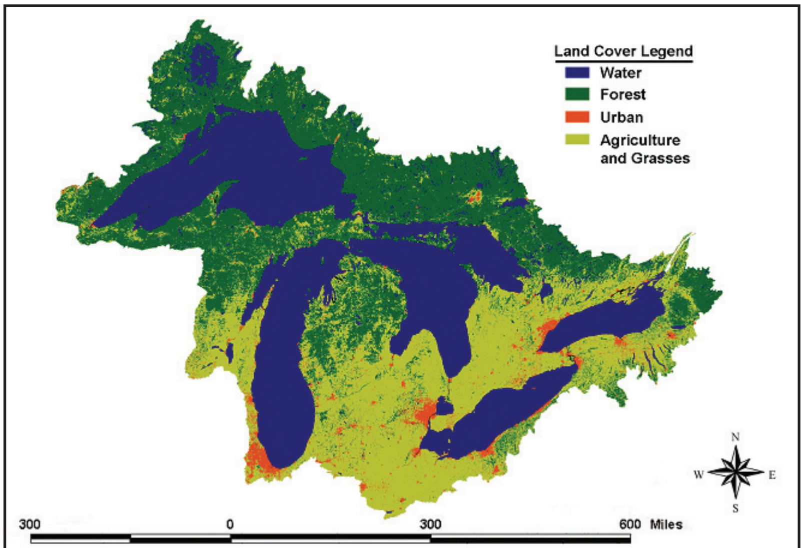

Figure 1. Binational land use data for 1990s.
Source: Zhang, Y. and B. Guindon. 2005. Landscape analysis of human impacts on forest fragmentation in the Great Lakes region. Can. J. Remote Sensing. 31(2):153-166

More recently, finer-resolution satellite imagery is allowing 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 26-category classification scheme (Figure 2) 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. 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:

Land Cover Type	Area in Hectares	Percentage of Total Land
Open Water	1,222,481*	4.20%
Low Intensity Residential	412,378	1.40%
High Intensity Residential	136,533	0.50%
TIGER Roads (1992)	1,675,899	5.80%
Commercial/Industrial	232,572	0.80%
Bare Rock/Sand/Clay	13,127	<0.1%
Quarries/Strip Mines/Gravel Pits	42,630	0.20%
Transitional	66,607	0.20%
Deciduous Forest	7,723,316	26.80%
Evergreen Forest	1,533,177	5.30%
Mixed Forest	1,790,038	6.20%
Shrubland	53,328	0.20%
Orchards/Vineyards/Other	216	<0.1%
Grasslands/Herbaceous	408,910	1.40%
Pasture/Hay	3,818,427	13.30%
Row Crops	6,801,486	23.60%
Small Grains	4,321	<0.1%
Urban/Recreational Grasses	102,940	0.40%
Emergent Herbaceous Wetlands	681,884	2.40%
Unconsolidated Shore	5,481	<0.1%
Lowland Grasses	139,226	0.50%
Lowland Scrub/Shrub	516,811	1.80%
Lowland Conifers	743,233	2.60%
Lowland Mixed Forest	678,830	2.40%
TOTAL	**28,803,849**	

* preliminary estimate

Table 1. Land Cover type, area, and percentage of total land for the U.S. Great Lakes basin. (*Preliminary estimate)
Source: Natural Resources Research Institute, University of Minnesota - Duluth

The remote-sensing data from satellite imagery needs to be validated with field sampling data. Satellite data can be difficult to interpret; thus there is often difficulty in distin guishing among various land use classes.

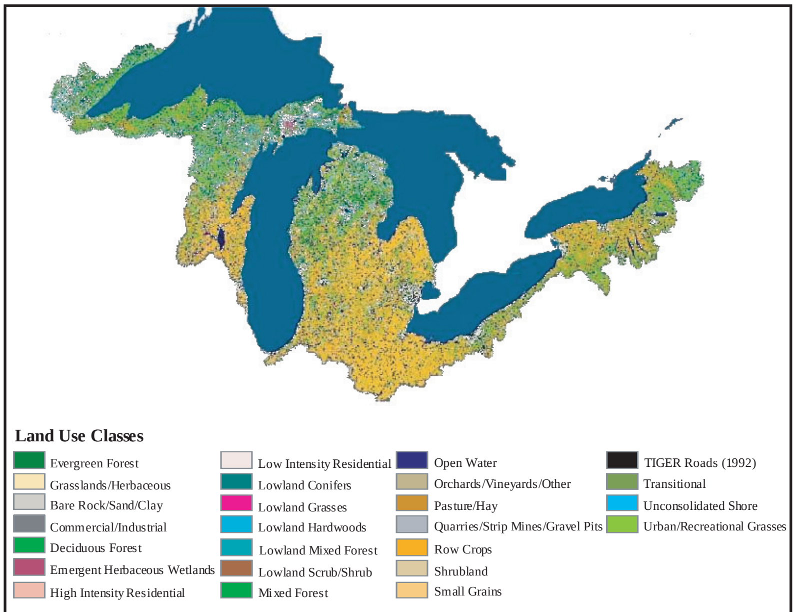

Figure 2. Land use in the U.S. Great Lakes basin.
Source: Natural Resources Research Institute, University of Minnesota - Duluth. Based on the National Land Cover Database (1992) of the U.S. Geological Survey (USGS) and other data sets

Forest inventories present a key source of field data on land use. The Ontario Ministry of Natural Resources (OMNR) relies on a combination of aerial photography and field sampling for its Forest Resources Inventory database. The following data for the Canadian Great Lakes basin are a mosaic of data collected between 1978 and 2001:

Land Cover Type	Area in Hectares	Percentage of Total Land
Productive Forest	13,045,401	60.20%
Open Muskeg	486,235	2.20%
Treed Muskeg	226,023	1.00%
Brush/Alder	201,954	1.40%
Grass/Meadow	644,473	3.00%
Developed Agricultural Land	3,124,074	14.40%
Rock	274,509	1.30%
Unclassified (mostly urban)	868,054	4.00%
Water	2,713,558	12.50%
TOTAL	**21,674,181**	

Table 2. Land cover type, area and percentage of total land in the Canadian Great Lakes basin.
Source: Ontario Ministry of Natural Resources (OMNR), Forest Resources Inventory database

The U.S. Department of Agriculture (USDA) Forest Service also has a field sampling protocol, the Forest Inventory and Analysis database. The following data is for the U.S. Great Lakes basin (Figure 3). In six of the eight Great Lakes states, data were collected in 2002; Michigan data is from 2001, while Ohio data is from 1991:

Land Cover Type	Area in Hectares	Percentage of Total Land
Forest	14,746,054	46.60%
Non-forest	14,981,127	47.30%
Non-census Water	206,576	0.70%
Census Water	1,724,577	5.50%
Denied Access	8,467	<0.1%
Hazardous	4,101	<0.1%
TOTAL	**31,670,902**	

Table 3. Forest and non-forest land cover type, area and percentage of total for the U.S. Great Lakes basin.
Source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis database

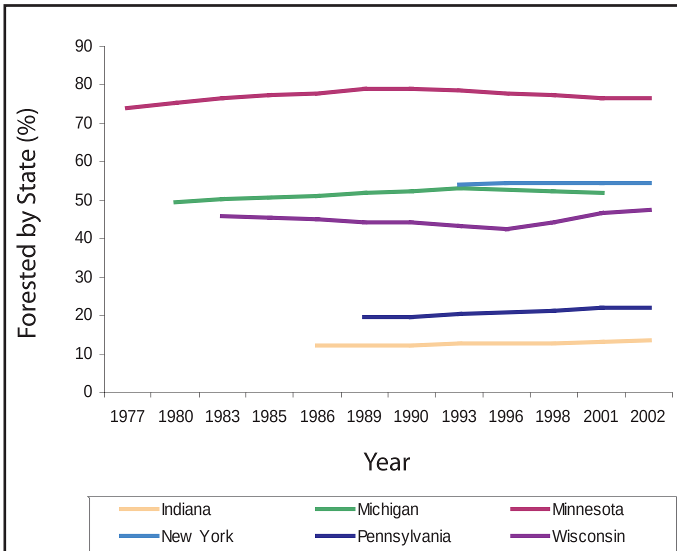

Figure 3. Percentage of land under forest cover in the U.S. Great Lakes basin, by state, 1977-2002. Includes only the portion of each state within the watershed.
Source: U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis database

USDA data from the past quarter-century are also available, enabling an analysis of land conversion in the U.S. Great Lakes basin over time. Due to the different reporting cycles in the eight states, a uniform baseline cannot be established for basin-wide analysis. However, a state-by-state analysis reveals that forest cover has generally been increasing across the basin in recent decades, while non-forest areas have correspondingly decreased.

It should be noted that the data sets discussed in this report were developed independently under different protocols. Making direct comparisons among them will require closer coordination of survey methods and data definitions.

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.

Acknowledgments
Author: Mervyn Han, Environmental Careers Organization, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office.

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.

Authors' Commentary
Land classification data must be standardized. The resolution should be fine enough to be useful at lake watershed and sub-watershed levels.

Brownfields Redevelopment

Indicator #7006

This indicator report is from 2003.

Assessment: Mixed, Improving

Data from multiple sources are not consistent.

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

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. These 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.

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. Most states track the amount of funding assistance provided as well as the number of sites that have been redeveloped. 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. Adding up state and provincial information to come up with a brownfields figure that represents the collective eight states and two provinces is challenging at best. 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 and Quebec indicate that, as of August, 2002, a total of 12,992 hectares (32,103 acres) have been remediated in these states and provinces alone, and approximately 1,862 hectares (4,600 acres) were remediated between 2000-2002. Available data from eight Great Lakes states and Quebec indicates that more than 24,000 brownfields sites have participated in brownfields clean-up programs since the mid-1990s, although the degree of "remediation" varies considerably.

Figure 1. Redeveloped brownfield site, Erie Front Street Complex, Pennsylvania.
Source: Pennsylvania Department of Environmental Quality

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. 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 ongoing 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 conversion, data should be collected that will enable an evaluation of each of these activities.

Acknowledgments

Author: Victoria Pebbles, Senior Project Manager, Transportation and Sustainable Development, Great Lakes Commission, Ann Arbor, MI, vpebbles@glc.org, www.glc.org. With assistance from Becky Lameka and Kevin Yam, Great Lakes Commission, Ann Arbor, MI.

Sources

Selected Annual Reports of state cleanup programs.

Personal communication with Great Lakes State Brownfield/Voluntary Cleanup Program Managers.

Authors' Commentary

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).

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-

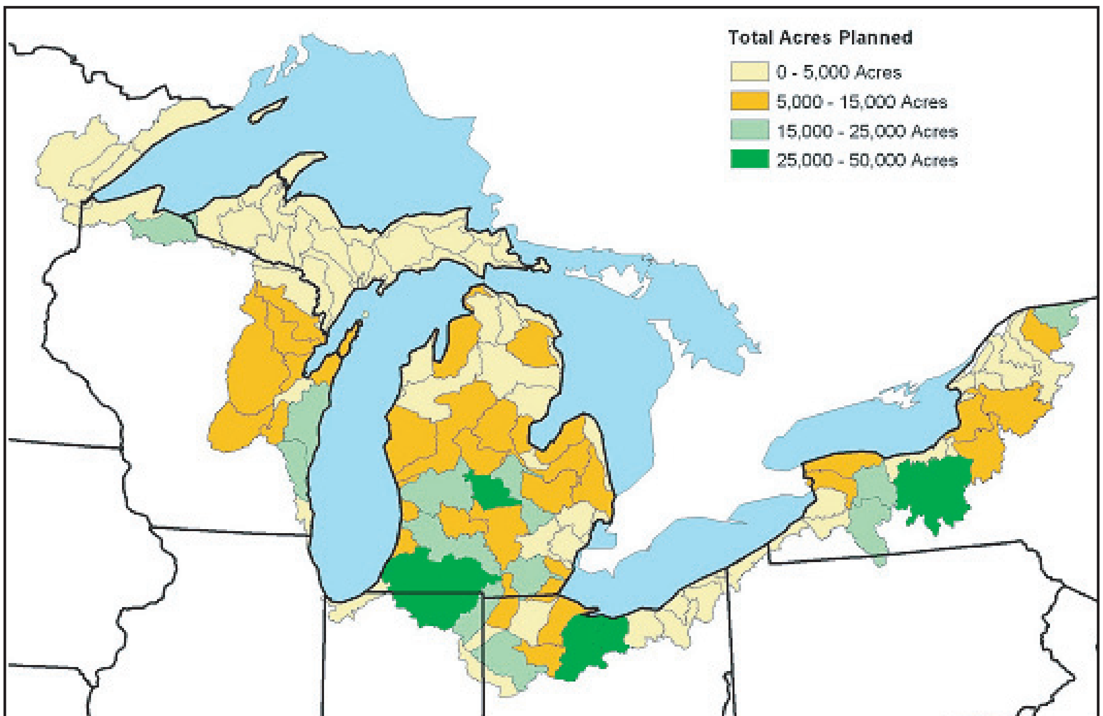

Figure 1. Acres of cropland in U.S portion of the basin covered under a conservation plan, 2003.
Source: Natural Resource Conservation Service, U.S. Department of Agriculture

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.

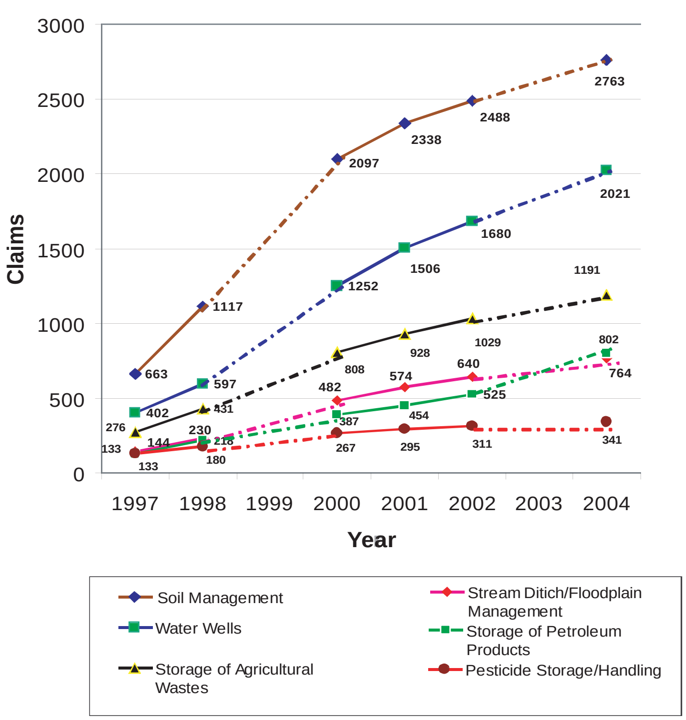

Figure 2. EFP: Cumulative Number of Incentive Claims by Worksheet (Issues). Six of 23 worksheets/issues are represented here - these six worksheets represent 70% of all EFP incentive claims. Three worksheets (Soil, Water and Storage of Agricultural Wastes) represent significant environmental actions 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.

Acknowledgments

Authors: Peter Roberts, Water Management Specialist, Ontario

Ministry of Agriculture and Food (OMAF), Guelph, Ontario Canada, peter.roberts@omaf.gov.on.ca;
Ruth Shaffer, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), ruth.shaffer@mi.usda.gov; and
Roger Nanney, United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), roger.nanney@in.usda.gov.

Sources

Ontario Soil and Crop Improvement Association. 2004. Environmental Farm Plan Database.

Economic Prosperity

Indicator #7043

This indicator report is from 2003.

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.

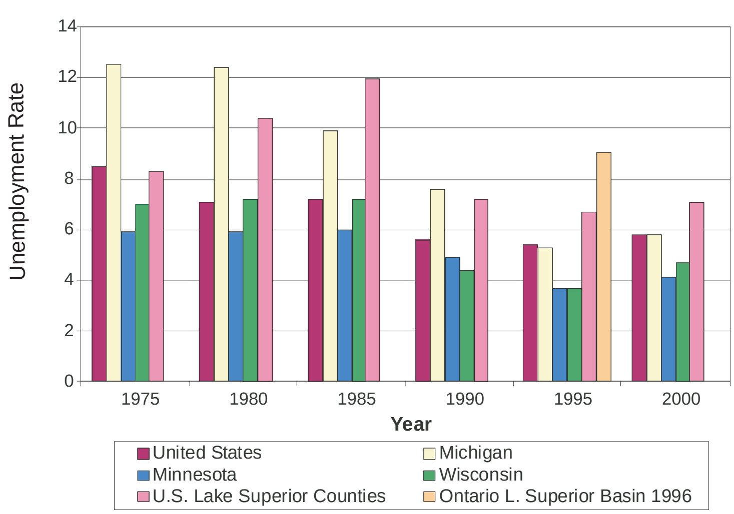

Figure 1. Unemployment rate in the U.S. (national), Michigan, Wisconsin, and the U.S. portion and Ontario portion of the Lake Superior basin, 1975-2000.
Source: U.S. Census Bureau and Statistics Canada

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.

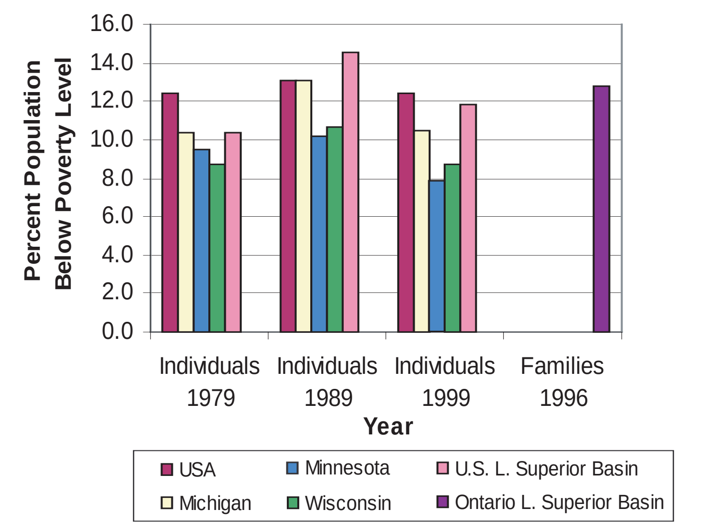

Figure 2. Individuals below poverty level in the U.S. (national), Michigan, Wisconsin, and the U.S. Great Lakes basin counties, 1979-1999, and families below poverty level in Ontario Great Lakes basin subdivisions, 1996.
Source: U.S. Census Bureau and Statistics Canada

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.

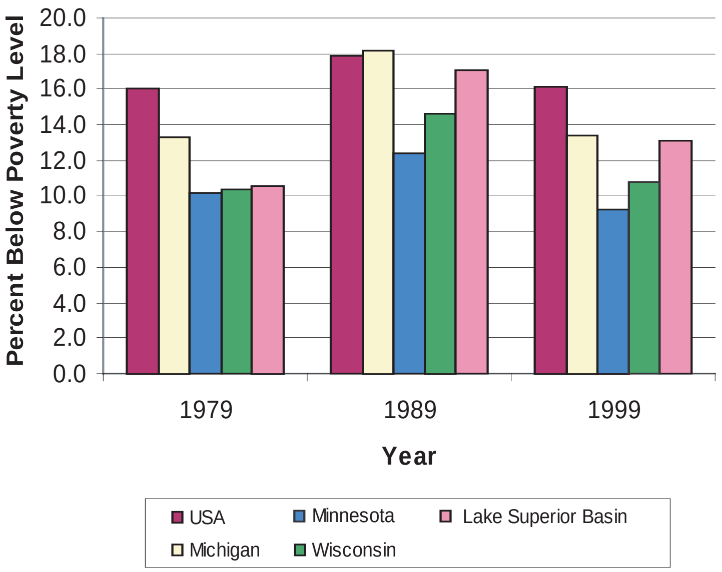

Figure 3. Children under age 18 below the poverty level, 1979-1999, U.S. (national), Michigan, Minnesota, Wisconsin and U.S. portion of the Lake Superior basin.
Source: U.S. Census Bureau

Sources

GEM Center for Science and Environmental Outreach. 2000. *Baseline Sustainability Data for the Lake Superior Basin: Final Report to the Developing Sustainability Committee, Lake Superior Binational Program, November 2000*. Unpublished report, Michigan Technological University, Houghton, MI. http://emmap.mtu.edu/gem/community/planning/lsb.html.

Statistics Canada. 1996. *Beyond 20/20 Census Subdivision Area Profiles for the Ontario Lake Superior Basin*.

U.S. Census Bureau. 2002. *Population by poverty status in 1999 for counties: 2000*. http://www.census.gov/hhes/poverty/2000census/poppvstat00.html.

U.S. Census Bureau. *State & County Quick Facts 2000*. Table DP-3. Profile of Selected Economic Characteristics. http://censtats.census.gov/data/MI/ 04026.pdf#page=3.

U.S. Census Bureau. *USA Counties 1998 CD-ROM* (includes unemployment data from Bureau of Labor Statistics).

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.

Ground Surface Hardening

Indicator #7054

Note: This is a progress report towards implementing this indicator.

Assessment: Not Assessed

The available information are incomplete, or outdated.

Purpose

- To indicate the degree to which development is affecting natural water drainage and percolation processes, thus causing erosion and other effects through high water levels during storm events and reducing natural groundwater regeneration processes; and
- To measure the impacts of land development on aquatic systems.

Ecosystem Objectives

A goal for the ecosystem is sustainable development. This would entail minimizing the quantities of impervious surface by using alternatives for replacement and future development.

State of the Ecosystem

Background

Ground surface hardening, or imperviousness, is the sum of area of roads, parking lots, sidewalks, roof tops and other impermeable surfaces of the urban landscape is a useful indicator with which to measure the impacts of land development on aquatic ecosystems (Center for Watershed Protection 1994).

Information on ground surface hardening in the Great Lakes basin is currently in the development stage. Different organizations are working towards developing effective systems of analyzing the status of this indicator. The use of technology such as Landsat imagery and Geographic Information Systems (GIS) applications are being utilized in efforts to evaluate the current state. The instruments on the Landsat satellites have acquired millions of images. These images form a unique resource for applications in agriculture, geology, forestry, regional planning, education, mapping, and global change research. This type of information will help illustrate the land use qualities of the Great Lakes basin.

In attempts to obtain information for this indicator many avenues were explored. Within Ontario, the Ontario Ministry of the Environment, Conservation Authorities and municipalities of different sizes were contacted for a random survey to see what information was available. Each organization had very little available information on impervious surfaces.

The Ontario Ministry of Natural Resources is in the process of implementing a project called Southern Ontario Land Resource Information System (SOLRIS). SOLRIS is a mapping program designed to accurately measure the nature and extent of Southern Ontario's natural resources and will be used to track changes to the natural, rural and urban landscape (Mussakowski 2004). SOLRIS integrates existing base resource information and advanced GIS and remote sensing techniques to derive a comprehensive land cover database. SOLRIS is attempting to complete the assembly of all layers into comprehensive land cover/use mapping by 2006 and will continue to upgrade on 5 or 10 year intervals.

Recently, Christopher Elvidge of the U.S. National Oceanic and Atmospheric Administration's National Geophysical Data Center in Boulder, Colorado, along with colleagues from several universities and agencies produced the first national map and inventory of impervious surface areas (ISA) in the United States. The new map is important, because impervious surface areas affect the environment. The qualities of impervious materials that make them ideal for construction also create urban heat islands by reducing heat transfer from the Earth's surface to the atmosphere. The replacement of heavily vegetated areas by ISA also reduces the sequestration of carbon from the atmosphere (Elvidge 2004).

Pressures

Growth patterns in North America can be generalized, with few exceptions, as urban sprawl. As our cities continue to grow outwards there is a growing dependency on personal transportation. This creates a demand for more roads, parking lots and driveways. Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other sources. Imperviousness represents the imprint of land development on the landscape (Center for Watershed Protection 1994).

A long-term, adverse impact to water quality could occur as a result of the continued and likely increase of nonpoint-source pollution discharge to stormwater runoff from roads, parking lots, and other impervious surfaces introduced into the area to accommodate visitor use. If parking lots, roads, and other impervious surfaces are established where none currently exist, then vehicle-related pollutants and refuse may accumulate. This impact could be mitigated to a negligible level through the use of permeable surfaces and vegetated or natural filters or traps for filtering stormwater runoff (National Park Service 2001).

Management Implications

Ground surface hardening is an important indicator in the Great Lakes basin that needs to be explored further. The information available for this indicator is incomplete, or outdated. With current technological advancements there are emerging methods of monitoring impervious surfaces, and hopefully within 5 years the data required for this report will be complete. Ground surface hardening has many detrimental effects on the environment; thus, it is essential to monitor and seek alternatives.

Acknowledgments
Author: Lindsay Silk, Environment Canada, Downsview, Ontario.

Sources

Center for Watershed Protection. 1994. The importance of imperviousness. *Watershed Protection Techniques* 1(3):100-111.

Elvidge, C. 2004. National Oceanic and Atmospheric Administration.

Mussakowski, R. 2004. Ontario Ministry of Natural Resources.

National Park Service. 2001. Merced Wild and Scenic River: Comprehensive Management Plan. http://www.cwp.org/SPSP/TOC.htm.

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.

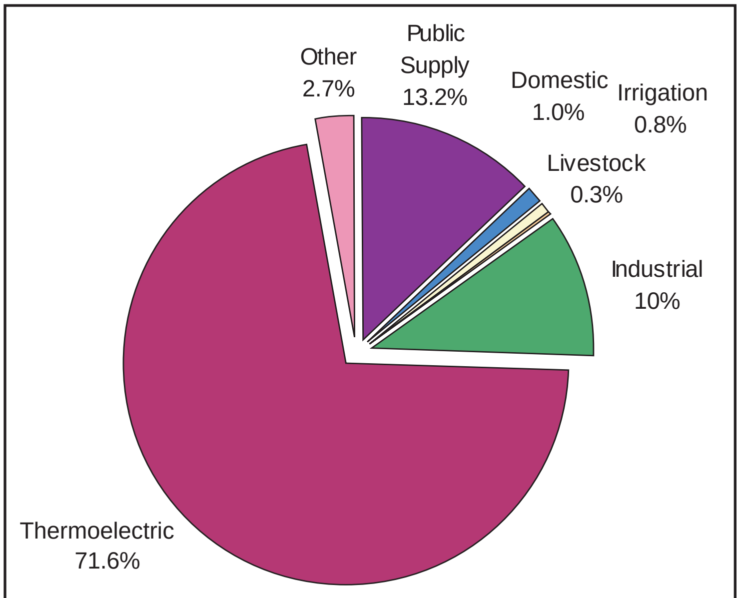

Figure 1. Water Withdrawals in the Great Lakes basin, by category as percentage of total, 2000.
Source: Great Lakes Commission, 2004

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).

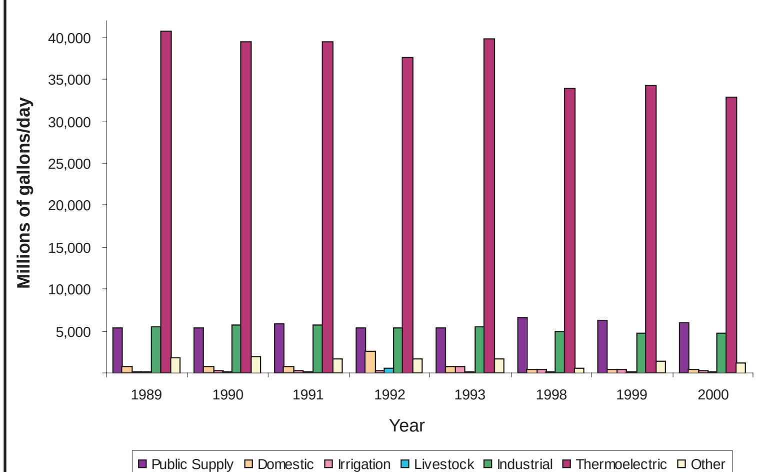

Figure 2. Great Lakes basin water withdrawals by category, 1989-1993 and 1998-2000.
Source: Great Lakes Commission, 1991-2004

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

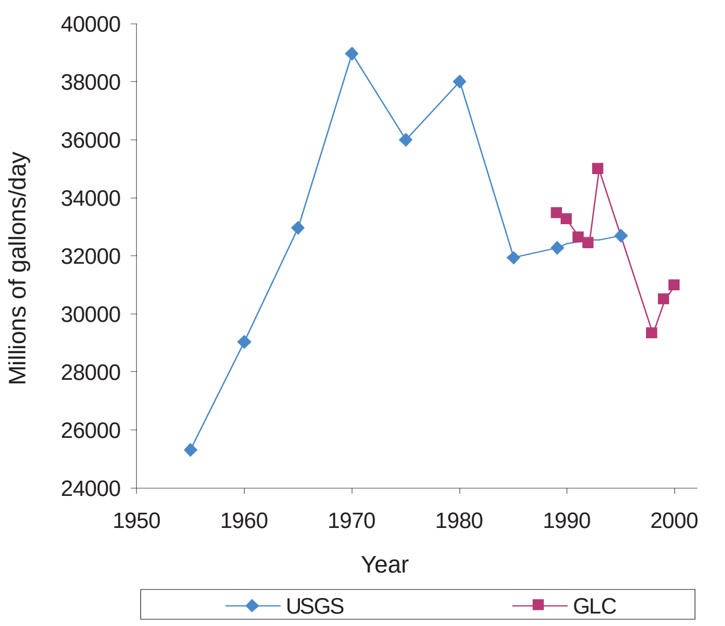

Figure 3. U.S. basin water withdrawals, 1950-2000.
Source: U.S. Geological Survey, 1950-2000. Great Lakes Commission (GLC).

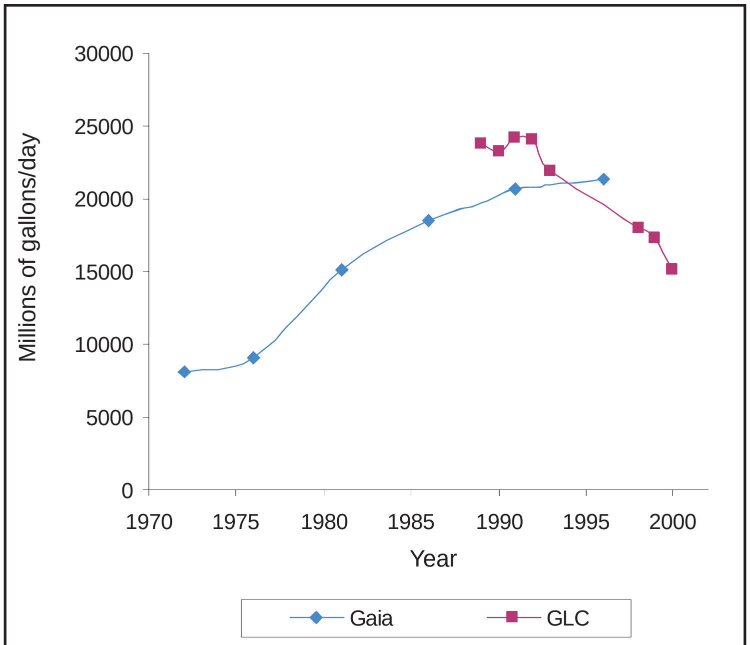

Figure 4. Canadian basin water withdrawals, 1972-2000.
Source: Gaia Economic Research Associates, 1999 (based on data from Environment Canada and Statistics Canada). Great Lakes Commission (GLC).

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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Site-specific water withdrawal data courtesy of James Casey (Illinois Department of Natural Resources), Sean Hunt (Minnesota Department of Natural Resources), Paul Spahr (Ohio Department of Natural Resources) and Ralph Spaeth (Indiana Department of Natural Resources). Ontario water permit map courtesy of Danielle Dumoulin (Ontario Ministry of Natural Resources).

Sources

Burke, D., Leigh, L., and Sexton, V. 2001. *Municipal water pricing, 1991-1999.* Environment Canada, Environmental Economics Branch.

Environment Canada. 2004. Great Lakes-St. Lawrence Regulation Office.

Gaia Economic Research Associates. 1999. *Water demands in the Canadian section of the Great Lakes basin 1972-2021*.

Great Lakes Commission (GLC). 2004. *Great Lakes regional water use database*. http://www.glc.org/wateruse/database/search.html.

Great Lakes Commission (GLC). 2003. *Toward a water resources management decision support system for the Great Lakes-St. Lawrence River basin: status of data and information on water resources, water use, and related ecological impacts*. Chapter.3, pp.58-62. http://www.glc.org/wateruse/wrmdss/finalreport.html.

Harris, J., and Tate, D. 1999. *Water demands in the Canadian section of the Great Lakes basin, 1972-2021.* Gaia Economic Research Associates (GERA) Report, Ottawa, ON.

Mills, E.L., Leach, J.H., Carlton, J.T., and Secor, C.L. 1993.

Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. *J. Great Lakes Res*. 19(1):1-54.
Renzetti, S. 1999. Municipal water supply and sewage treatment: costs, prices and distortions. *The Canadian Journal of Economics.* 32(3):688-704.

U.S. Geological Survey (USGS). 1950-2000. E*stimated Water Use in the United States: circulars published at 5-year intervals since 1950.* http://water.usgs.gov/watuse/.

U.S. Geological Survey (USGS). 1985. *Estimated use of water in the United States in 1985*. 68pp.

Visocky, A.P. 1997. Water-level trends and pumpage in the deep bedrock aquifers in the Chicago region, 1991-1995. Illinois State Water Survey Circular 182. Cited in International Joint Commission. 2000. *Protection of the waters of the Great Lakes: final report to the governments of Canada and the United States*. Chapter.6, pp 20-26. http://www.ijc.org/php/publications/html/finalreport.html.

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

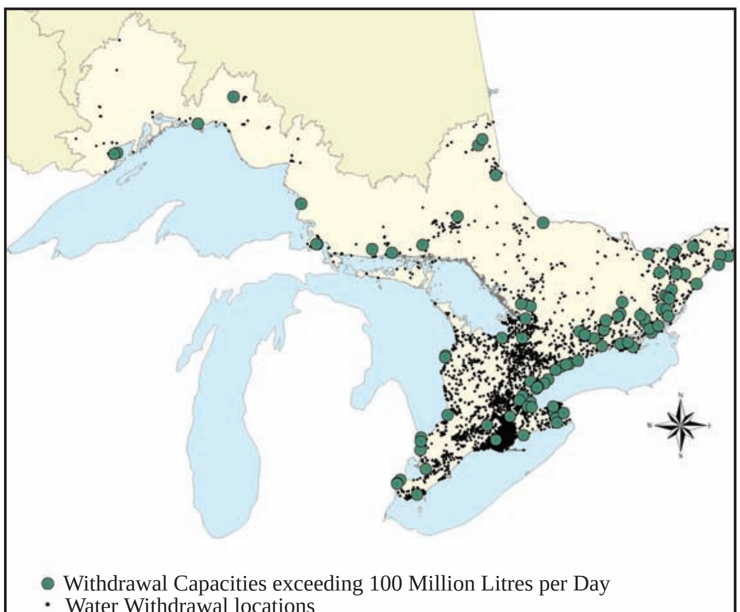

Figure 5. Permitted water withdrawal capacities in the Ontario portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources

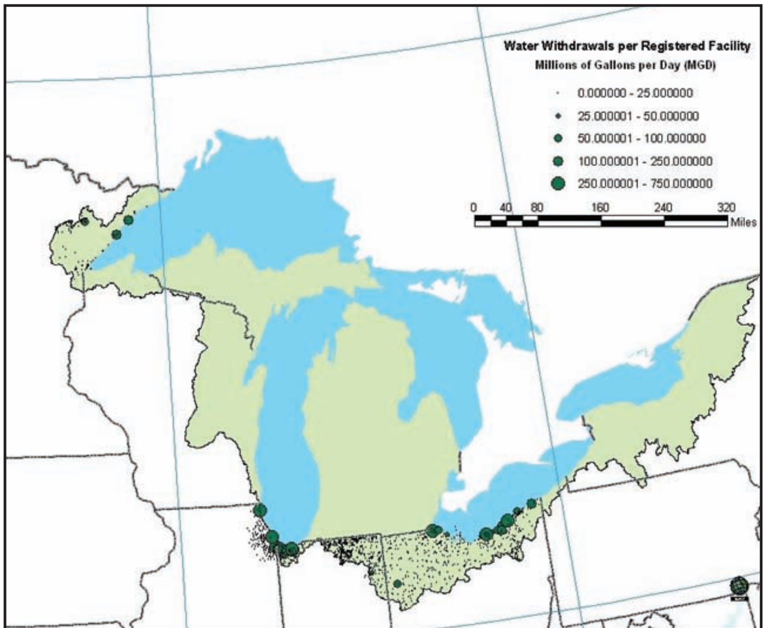

Figure 6. Map of Reported Water Withdrawals at Permitted or Registered Locations in Minnesota, Illinois, Indiana and Ohio. Source: IL Department of Natural Resources, MN Department of Natural Resources, OH Department of Natural Resources, IN Department of Natural Resources

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.

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

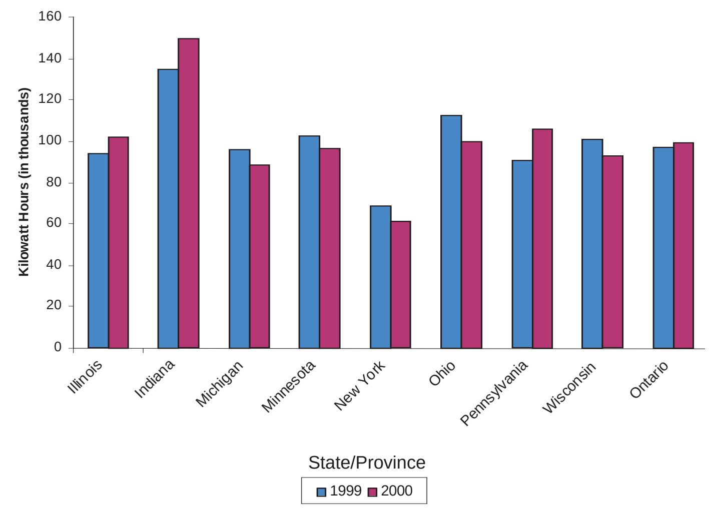

Figure 1. Total energy consumption per capita 1999-2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

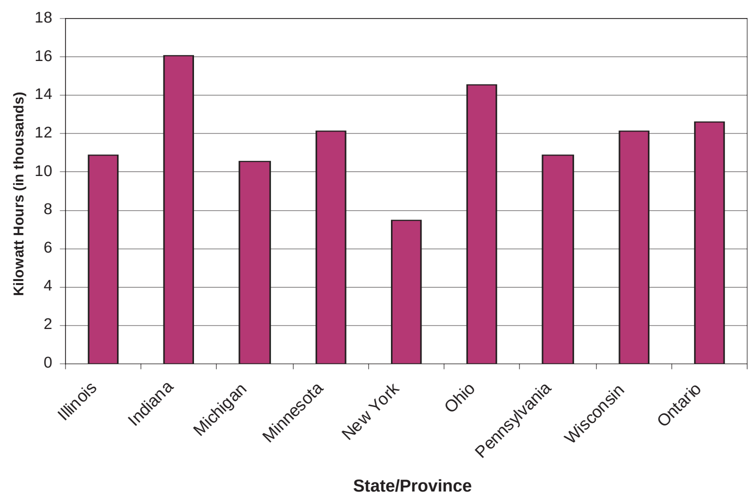

Figure 2. Electric energy consumption per capita 2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

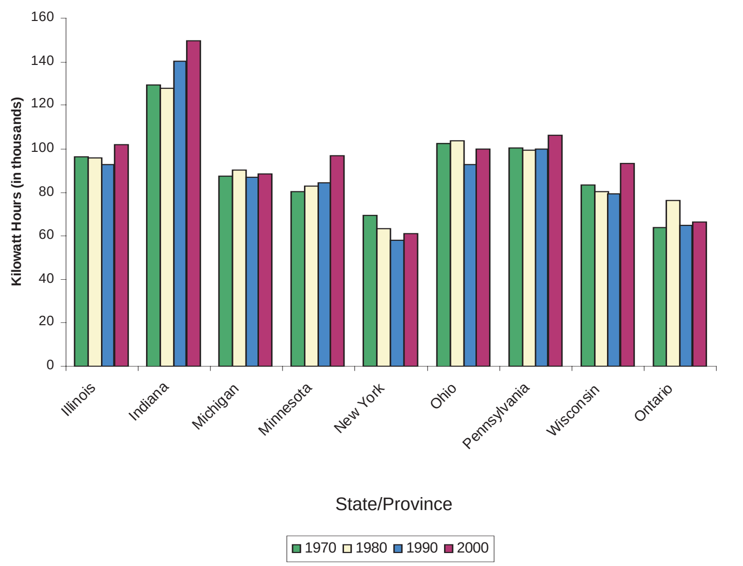

Figure 3. Total per capita energy consumption 1970-2000.1 MWh = 1000 kWh. Other energy sources include geothermal, wind, photovoltaic and solar energy. The Ontario data do not include the electricity generation sector due to an absence of data for this sector until 1978.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

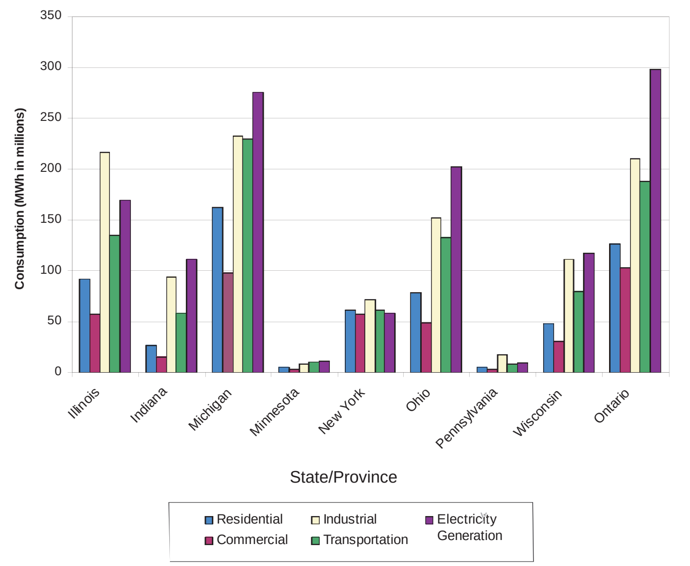

Figure 4. Secondary energy consumption within the Great Lakes basin by sector. Note: all data are from 2000, although 2002 data from Ontario are discussed in the report.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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.

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

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.

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

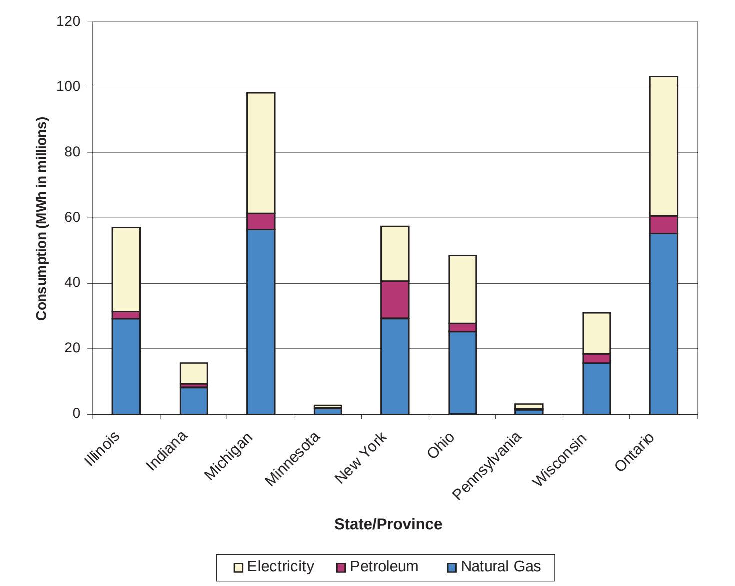

Figure 5. Commercial sector energy consumption by source, 2000. Wood and coal were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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).

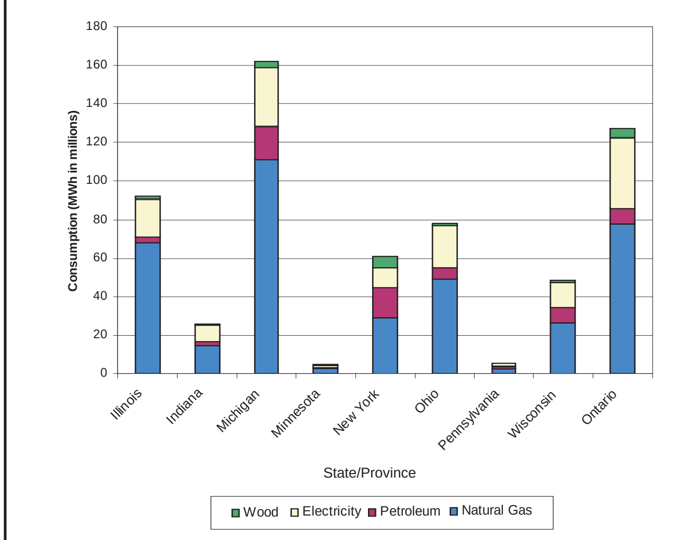

Figure 6. Residential sector energy consumption by source, 2000. Coal, geothermal, and solar energy were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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).

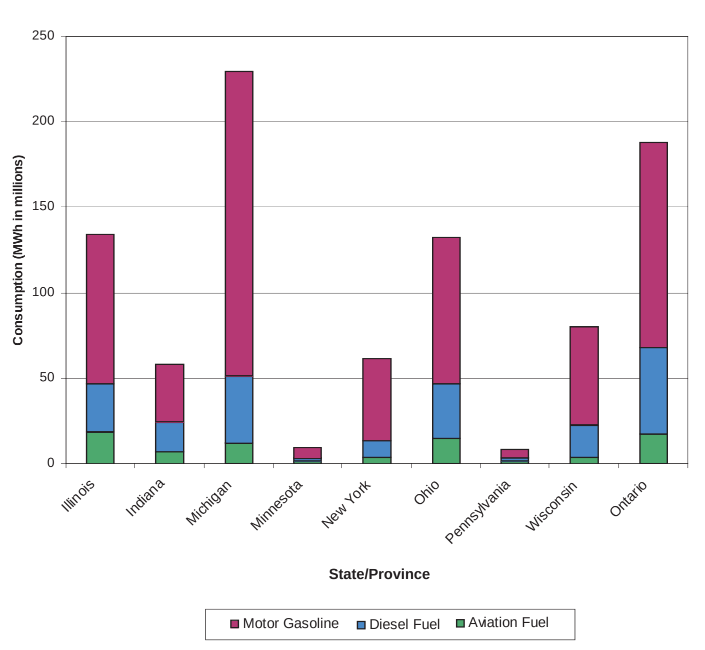

Figure 7. Transportation sector energy consumption by source, 2000. Natural gas and electricity were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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.

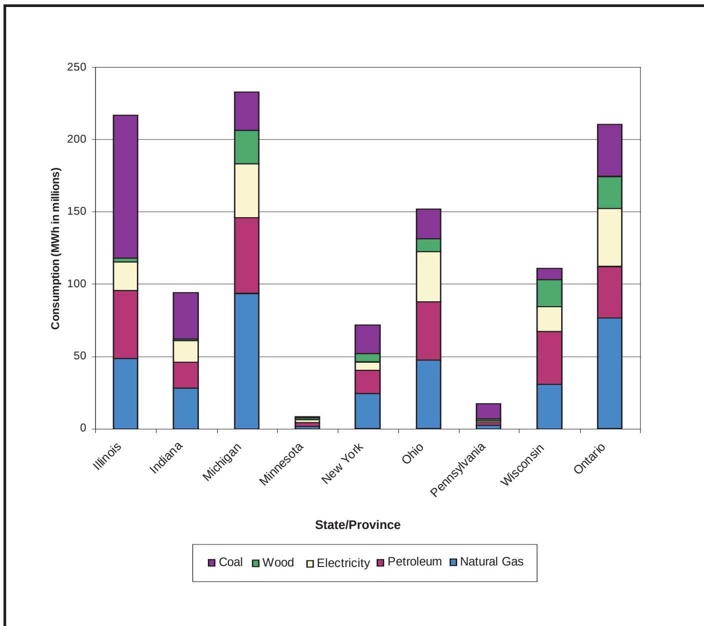

Figure 8. Industrial sector energy consumption by source, 2000. Hydroelectric power was a minor source in this sector. U.S. data for wood include wood waste.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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

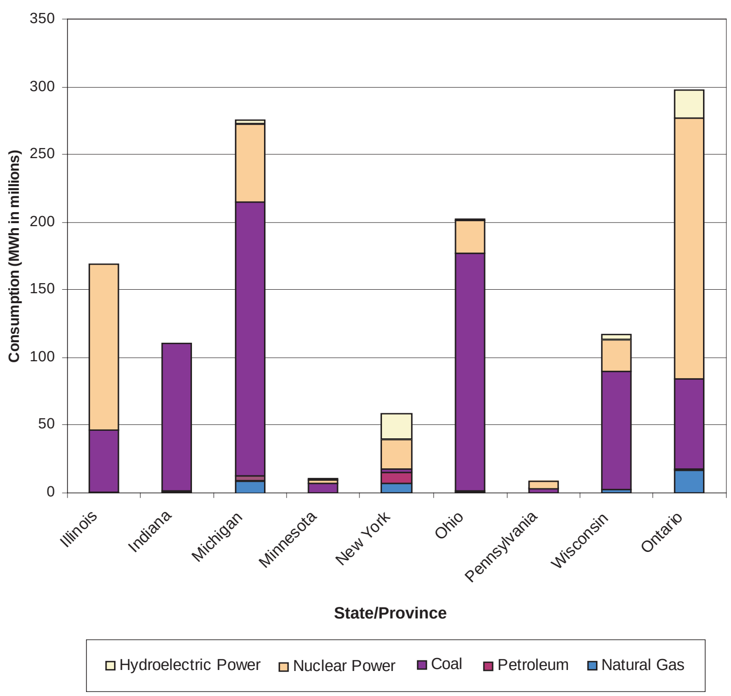

Figure 9. Electricity generation sector energy consumption by source, 2000. Wood and wood waste were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000)

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
Authors: Susan Arndt, Environment Canada, Ontario Region, Burlington, ON;
Christine McConaghy, Oak Ridge Institute for Science and Education, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL; and Leena Gawri, Oak Ridge Institute for Science and Education, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL.

Sources

Canada and U.S. Country Analysis Briefs. 2005. *Energy Information Administration*. http://www.eia.doe.gov/emeu/cabs/canada.html, last accessed October 4, 2005.

Energy Efficiency and Renewable Energy (EERE) Network News. 2004. *DOE Awards $94.8 Million to Weatherize Homes in 20 States*. U.S. Department of Energy. http://www.eere.energy.gov/news/news_detail.cfm/news_id=7438, last accessed October 4, 2005.

Environment Canada. 2003. *Environmental Signals, Canada's National Environmental Indicator Series 2003, Energy Consumption*. pp 56-59. http://www.ec.gc.ca/soer-ree.

Garman, D.K. 2004. *Administration's views on the role that renewable energy technologies can play in sustainable electricity generation.* United States Senate, Testimony before the Committee on Energy and Natural Resources. http://www.eere.energy.gov/office_eere/congressional_test_042704.html.

National Energy Policy Development Group (NEPDG). 2001. *Report of the National Energy Policy Development Group*. http://energy.gov/engine/content.do?BT_CODE=AD_AP.

Natural Resources Canada. 2002. *Energy Efficiency Trends in Canada 1990-2000.* http://oee.nrcan.gc.ca/neud/dpa/home.cfm.

Natural Resources Canada. *Comprehensive Energy Use Database*. http://oee.nrcan.gc.ca/neud/dpa/comprehensive_tables/.

Statistics Canada. 2000. *Human Activity and the Environment 2000*. [CDRom].

U.S. Census Bureau and Texas State Data Center. 2000. *U.S. 2000 decennial census data.* Department of Rural Sociology, Texas A&M University. http://www.census.gov/dmd/www/resapport/states/indiana.pdf and http://www.txsdc.tamu.edu/txdata/apport/hist_a.php.

U.S. Energy Information Administration (EIA). 2004. *State energy data 2000 consumption tables.* http://www.eia.doe.gov.

U.S. Environmental Protection Agency (USEPA). 2003. *ENERGY STAR - The power to protect the environment through energy efficiency.* http://www.energystar.gov/ia/partners/downloads/energy_star_report_aug_2003.pdf.

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.

Solid Waste Generation

Indicator #7060

This indicator report is from 2003.

Assessment: Mixed, Trend Not Assessed
Data from multiple sources are not consistent.

Purpose

- To assess the amount of solid waste generated per capita 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 generated in the basin needs to be assessed and ultimately reduced. Reducing volumes of solid waste is indicative of a more efficient industrial ecology and a more conserving society. Reduced waste volumes are also indicative of a reduction in contamination of land through landfilling and incineration and thus reduced stress on the ecosystem. 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 among the highest waste producers on Earth. However, both countries are working towards improvements in waste management by developing efficient strategies to reduce, prevent, reuse and recycle waste generation. Figure 1 displays the average per capita municipal solid waste generation in a selection of some of the most populated municipalities in the Ontario portion of the Great Lakes basin during 1991-2001. From this data, it is evident that there is a continual decline of municipal solid waste generation from 1991 to present. 1991 had the highest per capita generation at a value of 0.681 tons per person (0.618 tonnes per person). Per capita solid waste generation declined approximately 45% in 2001 to a value of 0.373 tons per person (0.338 tonnes per person). The rate of per capita municipal solid waste generation appears to have leveled off in the late 1990s. It must be noted that the apparent increase in per capita generation in 2000 may not be completely accurate since there was less data collected to obtain the average for 2000 as compared to 1999 and 2001. The decline in per capita solid waste generation in the early 1990s can be attributed to the increased access to municipal curbside recycling and the initiation of backyard and centralized composting programs in most Ontario municipalities.

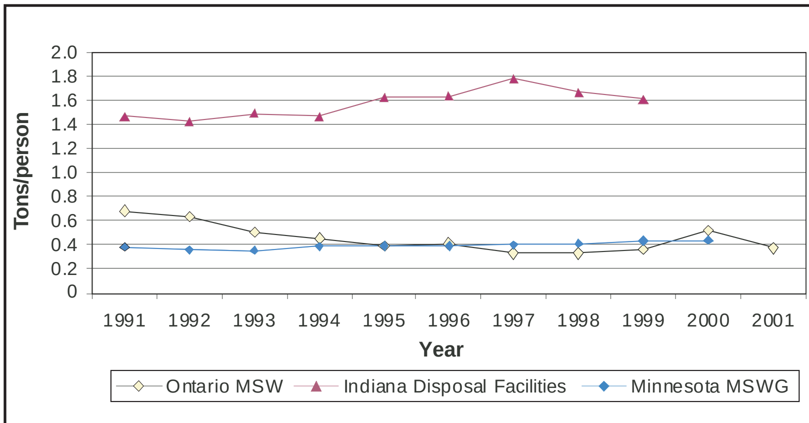

Figure 1. Average per capita solid waste generation and disposal (tons/person) from selected municipalities in Ontario, Indiana and Minnesota, 1991-2001. MSW = Municipal Solid Waste; MSWG = Municipal Solid Waste Generation.
Source: Indiana Department of Environmental Management, 2000; Minnesota Office of Environmental Assistance, 2000, Ontario data obtained from Statistics Canada, Environmental Account and Statistics Division, and Demography Division

Figure 1 also displays the average per capita municipal solid waste generation disposed in Minnesota's counties of the Great Lakes basin during 1991-2000. The data shows the amount of municipal solid waste generation disposed declined slightly from 1991 to 1993, and then increased from 0.386 tons per capita (0.350 tonnes per capita) in 1994 to 0.436 tons per capita (0.396 tonnes per capita) in 2000. The data suggests that these trends in municipal solid waste generation are not significant despite growth in population over the same time period. The counties of Cook, Lake and Pine represent the highest increase of per capita solid waste generation during 1993 to 2000. For example, in 1993 Cook County increased to 45% of the municipal solid waste generation.

Figure 1 also displays the average trends of the waste disposed per capita (in tons) in Indiana by estimated county of origin in a final disposal facility. The graph shows a 21% increase in per capita non-hazardous waste disposed between 1992 and 1998. From 1998 to 2000 there was a 9% decrease in the amount disposed.

The Illinois Environmental Protection Agency, Bureau of Land, reported the projected disposal capacity of the solid waste in sanitary landfills for 2000. The regional waste disposed and landfill capacity for the Great Lake basin counties was 1.7 cubic yards (1.3 cubic metres) per person. This area has a per capita capacity below the state average. The municipal waste generated and recycled was 7.4 cubic yards (5.7 cubic metres) per person.

The Michigan Department of Environmental Quality reports on data of total waste disposed in Michigan landfills in per capita cubic yards from 1996 to 2001. In 1996 the solid waste landfilled per capita was 3.76 cubic yards (2.87 cubic metres) and in 2001 the value increased to 4.84 (3.70 cubic metres), showing a 32% increase of solid waste disposed in landfills.

New York Department of Environmental Conservation provided the State solid waste generation data from 1990 to 1998. The data reflects that the average per capita solid waste generation from 1990 to 1998 increased by 20%. The reusable tons in New York State increased approximately 30% of the waste disposed.

Region 3 of the Environmental Protection Agency in Pennsylvania provided the daily per capita amount of municipal solid waste generated in counties within the Great Lakes basin. In 1998 the municipal solid waste generated for Crawford County was 2.4 (pounds/person/day) (or 1.1 kg/person/day), 3.8 (or 1.7) for Erie County and 1.4 (or 0.6) for Potter County. In 1999 these numbers generally increased to 2.6 (or 1.2) for Crawford, 3.7 (or 1.7) for Erie and 2.6 (or 1.2) for Potter. The Pennsylvania Department of Environmental Protection provided the statewide municipal solid waste generation during 1988 to 2000 which showed an increase of 30% of the waste disposed.

The calculated average per capita municipal waste landfilled in Wisconsin in 2001 was 1.85 tons (1.68 tonnes), as reported by the Department of Natural Resources. The counties with the larger average values are those located closer to Lake Michigan. For example, Calumet average value is 4.87 tons (4.42 tonnes) per person, Dodge is 4.20 tons (3.81 tonnes), Green Lake is 12.11 tons (10.99 tonnes), Kenosha is 3.80 tons (3.45 tonnes) and Manitowoc 4.35 tons (3.95 tonnes) per person.

The Ohio Environmental Protection Agency collects data for residential and commercial solid waste management district landfill generated, disposed and recycled for each of the 88 counties, which are grouped into 52 single and multi-county districts. The Northeast District Office (NEDO) and the Northwest District Office (NWDO) are districts that include the counties in the Great Lakes basin. Figure 2 presents the average amount of NEDO and NWDO residential and commercial solid waste management district generated, disposed and recycled for 1999 and 2000. The solid waste disposed for NEDO increased by 3% over the two year period. The amount of solid waste generated increased by 6% for NWDO over the same time period. The recycled amount increased by 2% for NEWO and by 32% for NWDO from 1999 to 2000.

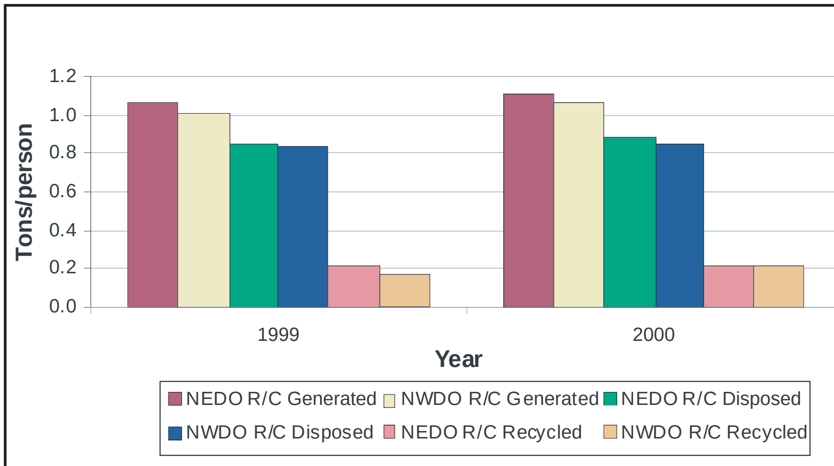

Figure 2. Ohio counties average per capita solid waste landfill facilities generated, disposed and recycled in the Great Lakes basin, 1999-2000. R/C = Residential and Commercial Solid Waste. NEDO = Northeast District Office, NWDO = Northwest District Office.
Source: Ohio Environmental Protection Agency, Division of Solid and Infectious Waste Management

Reuse and recycling are opportunities to reduce the amount of solid waste ending up in landfills or being incinerated. By examining recycling and waste diversion in Ontario, both the tonnage of municipal solid waste diverted from disposal and the number of households with access to recycling have increased in recent years (WDO 2001a).

Figure 3 shows the trends in residential recycling tonnages in Ontario (including areas outside of the Great Lakes basin) from 1992-2000 (WDO 2001). There has been a 41% increase in the

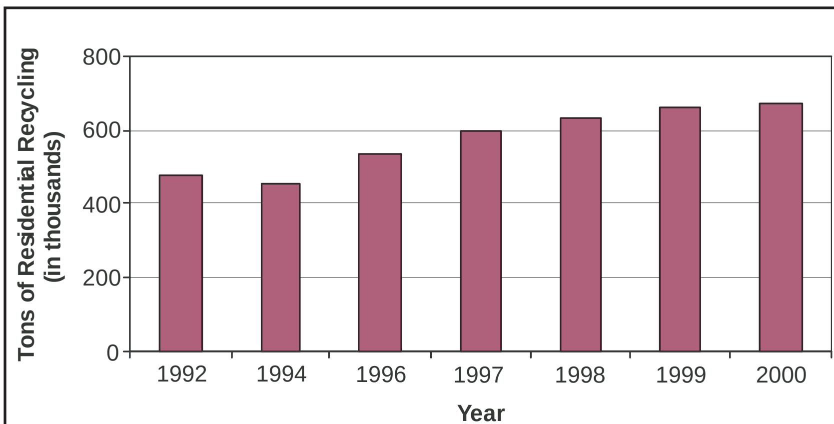

Figure 3. Residential recycling tonnage in Ontario, 1992-2000.
Source: Ontario Waste Diversion Organization (WDO), 2000

amount of residential recycling from 1992-2000, which may account for the reduced per capita solid waste generation displayed in recent years in Ontario municipalities.

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 landfill sites are filling up fast. In addition, the generation of municipal solid waste contributes to soil and water contamination and air pollution. It is estimated that far more residential solid waste is being generated each year, but a greater proportion is being recovered for recycling and reuse.

The state of the economy has a strong impact on consumption and waste generation. Waste generation continued to increase through the 1990s as economic growth continued to be strong (USEPA 2002). Much of this increase in waste generation in the 1990s was due to the booming economy (USEPA 2002). An economic growth results in more products and materials being generated. This growth should send a message for a larger investment in source-reduction activities. Source-reduction activities will help to save natural resources, will reduce the toxicity of wastes, will reduce costs in waste handling, and will make businesses more efficient.

Management Implications

There is a need to assess and determine which material makes up the majority of the municipal solid waste that is generated each year. This will help managers target waste reduction efforts towards limiting the amount of these products that make it through the waste stream. It would also be interesting to research how different waste reduction techniques can produce differing trends in solid waste reduction. For example, user pay (or pay as you throw away) unit-based pricing, is becoming a more acceptable method for financing residential waste management services and making households more directly responsible for their waste generation and disposal habits (WDO 2001b). Bag limits on waste are usually a first step many municipalities take in order to make the transition to user pay systems easier. User pay programs have gained momentum across most of Canada with most growth occurring in the mid to late 1990s. Imposing these limits encourages homeowners to be more conscious of the amount and type of waste generated as they now associate a financial cost with their consumptive behavior. It makes a homeowner personally responsible and encourages alternative waste diversion activities. Another example is an ambitious statewide campaign dedicated to educate the residents on the benefits of waste reduction and to demonstrate how solid waste can affect their own health and the health of their environment. In another case, a local government waste prevention program, consisting of a network of counties and cities, was organized to discuss and create methods to help in waste reduction activities that would better protect the state's environment and public health. Developing methods for standardizing information and for tracking waste will aid in improving the sharing of information and data statewide.

Acknowledgments

Authors: Martha I. Avilés-Quintero, U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL; and
Melissa Greenwood, Environment Canada, Downsview, ON.

Ontario data for the disposal of waste by province was obtained from Statistics Canada, Environmental Account and Statistics Division, and Demography Division.
http://www.statcan.ca/start.html.

Data collected are based on the values obtained by contacting the waste management departments of Ontario municipalities around the Great Lakes basin.

The recycling data collected from the province of Ontario, were adapted from the Municipal 3Rs in Ontario: 2000 Fact Sheet, published by the WDO – Ontario Waste Diversion Organization. http:///www.wdo.on.ca.

The United States data of municipal waste generated per capita, average, landfill capacity, disposed and recycled waste were collected by contacting the different State and Federal Agencies management departments and by searching their websites. The U.S. Environmental Protection Agency, Region 5, Pollution Prevention & Program Initiatives Section provided the contact list for the searching values. Some data were adapted using the counties on the Great Lakes basin and using the census-estimate populations to calculate the per capita generation, disposed and recycled.

Illinois data of the waste disposed and landfill capacity per capita in cubic yards by Region for 2000, was provided by the Illinois Environmental Protection Agency, Bureau of Land. Region 2 is the Chicago Metropolitan basin that includes counties in the Great Lakes basin. http://www.epa.state.il.us.

Indiana data of the municipal solid waste per capita for 2001, was obtained from Indiana Department of Environmental Management. Also, the 2000 Summary of Indiana Solid Waste Facility Data Report was used to calculate the waste disposed per capita. The census-estimate population for 1992-2000 by counties on the Great Lakes basin was used to obtain those values. http://www.in.gov.idem/land/sw/index.html.

Michigan data of the total solid waste disposed in Michigan

landfills per capita in cubic yards for 1996-2001, was provided by Michigan Department of Environmental Quality, Waste Management Division. The report was used and adapted to calculate the per capita amount using the census-estimated population for 1996-2001. http://www.deq.state.mi.us.

Minnesota data of the municipal solid waste generation per capita for 1991- 2000, was provided by the Minnesota Office of Environmental Assistance. The SCORE report is a full 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. http://www.moea.state.mn.us.

New York data of the solid waste generated and recycled in tons for 1990-1998, was provided by New York State Department of Environmental Conservation, Division of Solid and Hazardous Materials. The data was adapted to obtain the per capita generation with the census-estimate population per year. http://www.dec.state.ny.us.

Ohio data of disposed and recycled generated solid waste per capita in landfills for each solid waste management district for 1999- 2000, was provided by Ohio Environmental Protection Agency, Division of Solid Waste and Infectious Waste Management. The data for the Northeast and Northwest district offices was adapted by counties on the Great Lakes basins and census-estimate data population per year. http://www.epa.state.oh.us.

Pennsylvania data of the average per capita recycled generation rates was provided by Pennsylvania Department of Environmental Protection, Bureau of Land Recycling and Waste Management. http://www.dep.state.pa.us.

Wisconsin data of municipal waste landfill tons capacity for 2001, was provided by Wisconsin Department of Natural Resources, Bureau of Waste Management. http://www.dnr.state.wi.us.

Sources

Illinois Environmental Protection Agency. 2002. *Non-hazardous solid waste management and landfill capacity in Illinois.* Annual Landfill Capacity Report, Bureau of Land. IEPA/BOL/01-014. http://www.epa.state.il.us/land/landfill-capacity/index.html.

Indiana Department of Environmental Management. 2000. *Summary of Indiana Solid Waste Facility Data Report.* Office of Land Quality. http://www.state.in.us/idem/land/sw/qtrlyrpts/fars/far00.pdf.

Michigan Department Environmental Quality. 2002. *Report of solid waste landfilled in Michigan*. Waste Management Division. http://www.michigan.gov/deq/1,1607,7-135-3312_4123-47581—,00.html.

Minnesota Office of Environmental Assistance. 2002. *Report on 2000 SCORE programs, a summary of waste management in Minnesota.* http://www.moea.state.mn.us/lc/score00.cfm.

Ontario Waste Diversion Organization (WDO). 2001a. *Municipal 3Rs in Ontario: 2000 Fact Sheet*. http://www.wdo.on.ca, last accessed July 22, 2002.

Ontario Waste Diversion Organization (WDO). 2001b. *The waste diversion impacts of bag limits and PAYT systems in North America.* http://www.wdo.on.ca, last accessed August 2, 2002.

Ontario Waste Diversion Organization (WDO). 2001c. *Waste diversion and concept testing, qualitative and quantitative findings*. http://www.wdo.on.ca, last accessed August 2, 2002.

Statistics Canada. 2001. *Disposal of waste by Province and Territory, 2000 preliminary estimates.* Environmental Account and Statistics Division, and Demography Division. http://www.statcan.ca/start.html, last accessed June 24, 2002.

United States and Canada. 1987. *Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987*. Ottawa and Washington.

U.S. Census Bureau. *1990's, 2000's Population Estimates.* http://www.census.gov/popest/estimates.php.

U.S. Environmental Protection Agency (USEPA). 2002. *Municipal solid waste in the United States: 2000 facts and figures.* Office of Solid Waste and Emergency Response (5305N) EPA530-R-02- 001. http://www.epa.gov, last accessed August 2, 2002.

Authors' Commentary

The province of Ontario has set a challenging task for the Waste Diversion Organization to reach a 50% waste diversion. Ontario residents diverted a total of 29% of 1.23 million tons (1.12 million tonnes) of their residential waste from disposal in 1998. In order to achieve a 50% reduction in waste the following practices need to be encouraged: increasing financial support, expanding provincial 3R (reduce, reuse, recycle) regulations, changing societal habits and behavior towards waste generation, investing more into infrastructure and lastly, adoption of waste management user fees (WDO 2001c).

To report on this indicator in the future, data on waste diversion should be incorporated as well as waste generation. Examination of the changes in the amount of waste that is removed from the waste stream can be used to infer how the behavior of society is changing with regards to wasting resources and sustainable development.

During the process of collecting data from this indicator, it was found that most U.S. states and Ontario municipalities 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.

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

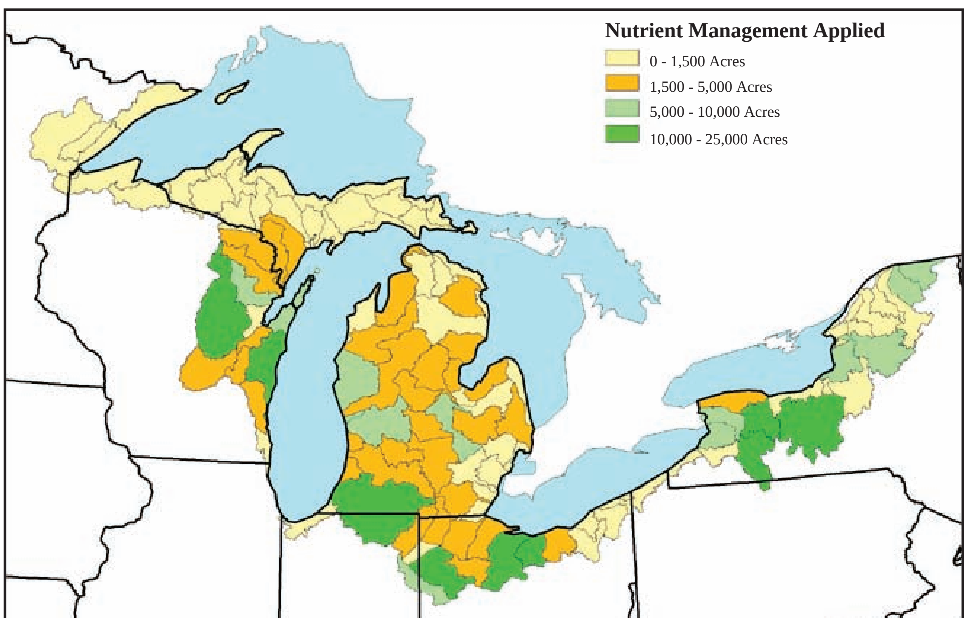

Figure 1. Annual U.S. Nutrient Management Systems total number of nutrient management plans developed annually for the U.S. portion of the basin, 2003.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Performance and Results Measurement System

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.

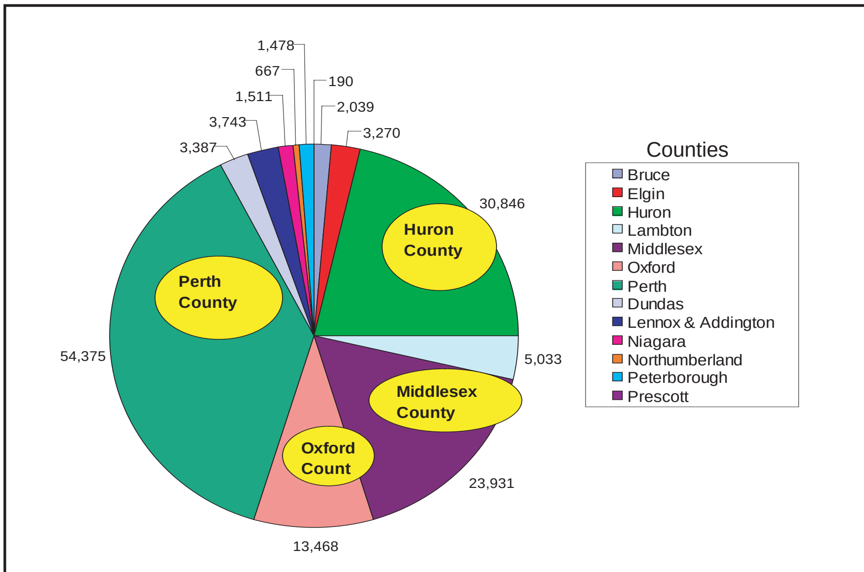

Figure 3. Cumulative acreage of Nutrient Management Plans for selected Ontario Counties in the basin. Over 75% NMP acreages found in Huron, Perth, Oxford and Middlesex Counties.
Source: Ontario Ministry of Agriculture and Food

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

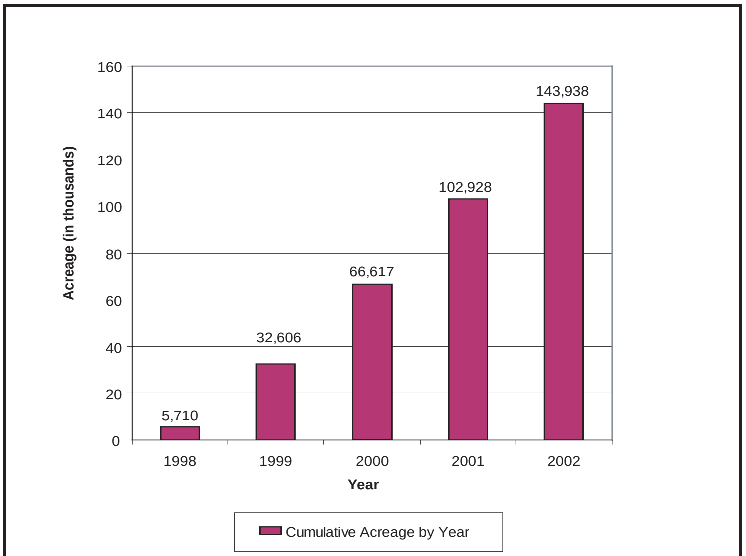

Figure 2. Nutrient Management Plans by Ontario County, 1998-2002.
Source: Ontario Ministry of Agriculture and Food

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.

Acknowledgments

Authors: Peter Roberts, Water Management Specialist, Ontario Ministry of Agriculture and Food, Guelph, Ontario Canada. peter.roberts@omaf.gov.on.ca;
Ruth Shaffer, U.S. Department of Agriculture, Natural Resource Conservation Service, ruth.shaffer@mi.usda.gov; and
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.

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-

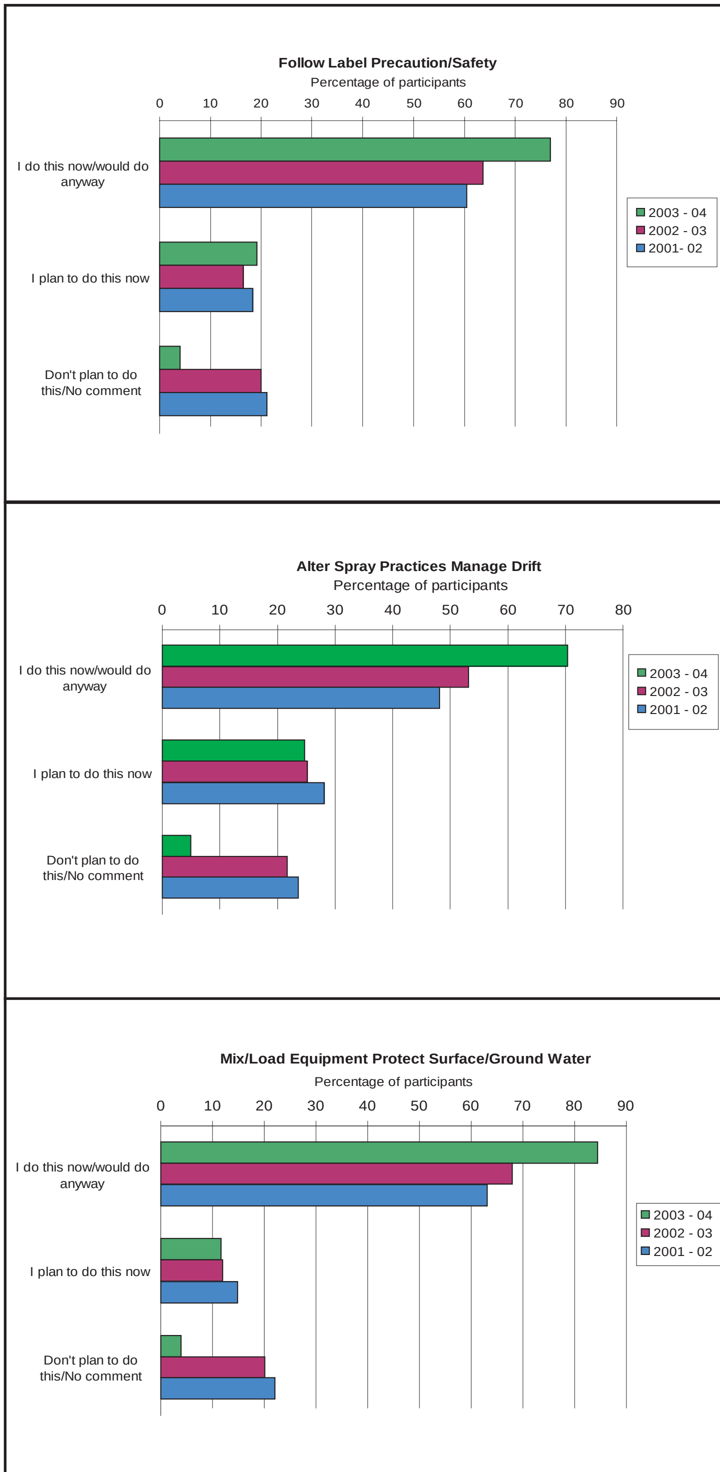

Figure 1. Ontario selected grower pesticide safety training course evaluation results from 2001-2004.
Source: Ontario Ministry of Agriculture and Food, Ontario Ministry of the Environment (OMOE) and the University of Guelph

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.

Sources

U.S. General Accounting Office (GAO). 1993. *Pesticides – Issues concerning pesticides used in the Great Lakes watershed*. GAO/RCED-93-128. Washington, DC. 44pp.

Ontario Ministry of the Environment (OMOE). 1995. *Water monitoring 1995*. Environmental Monitoring and Reporting Branch.

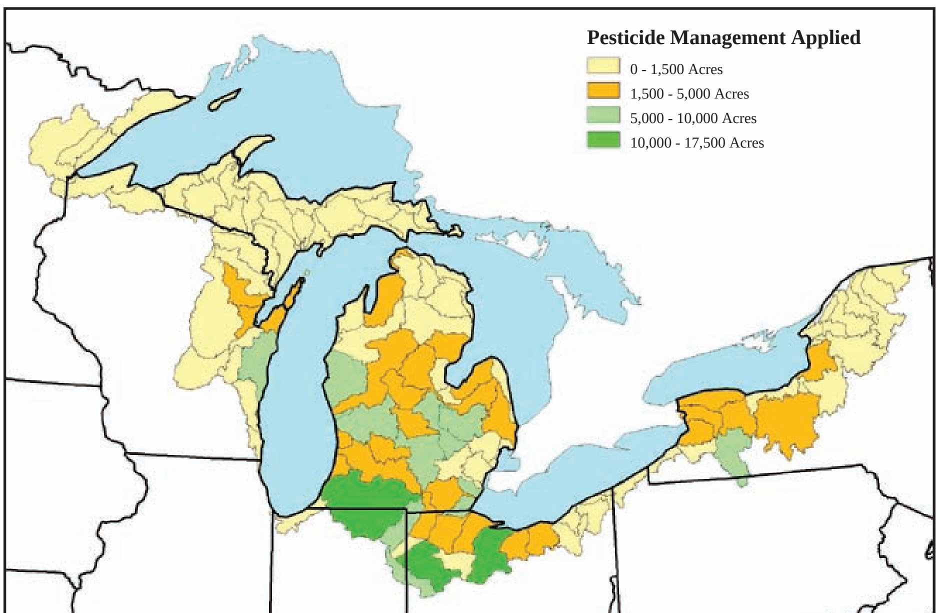

Figure 2. Annual U.S. Pesticide Management Systems Planned for 2003.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Performance and Results Measurement System

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.

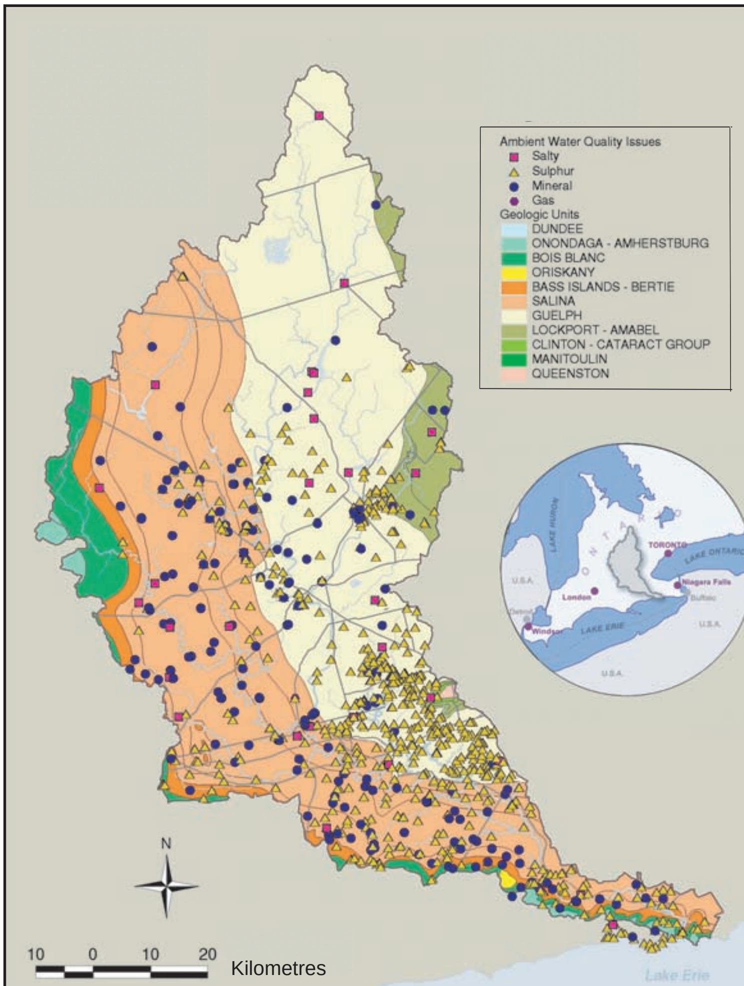

Figure 1. Bedrock wells with natural quality issues in the Grand River watershed.
Source: Grand River Conservation Authority

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.

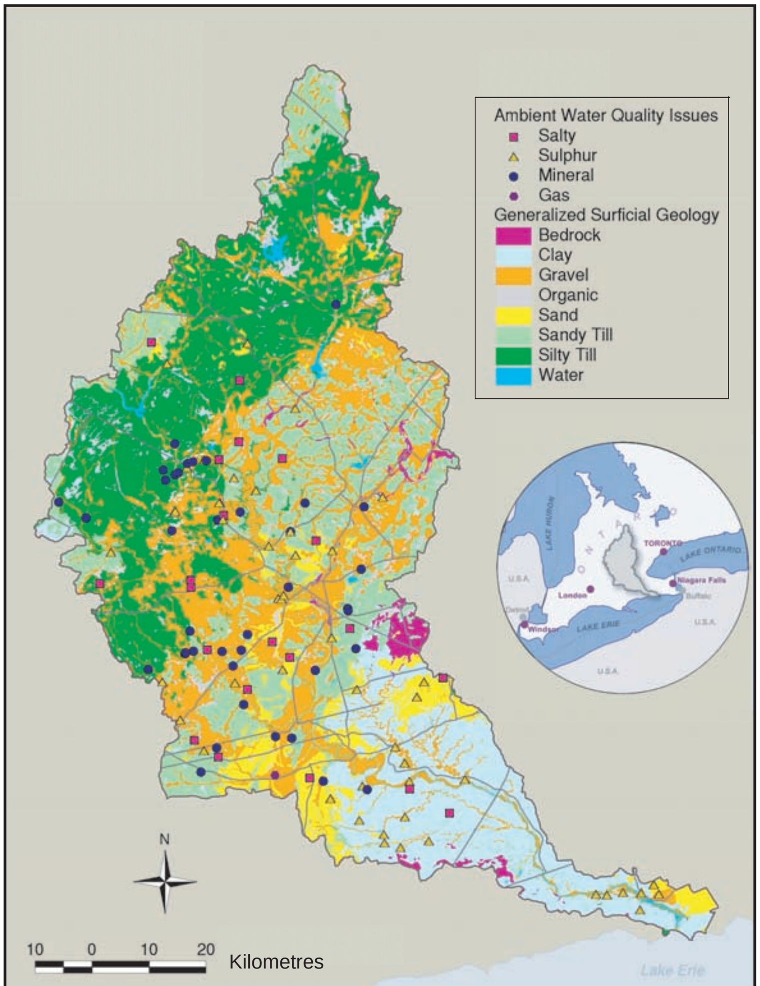

Figure 2. Overburden wells with natural quality issues in the Grand River watershed.
Source: Grand River Conservation Authority

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

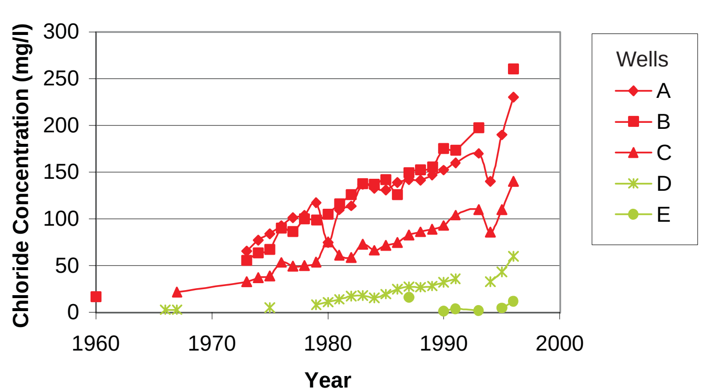

Figure 3. Chloride levels in selected groundwater wells in the Regional Municipality of Waterloo. Red indicates wells from one area/well field. Green indicates wells from a different area/well field.
Source: Stanley Consulting, 1998

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

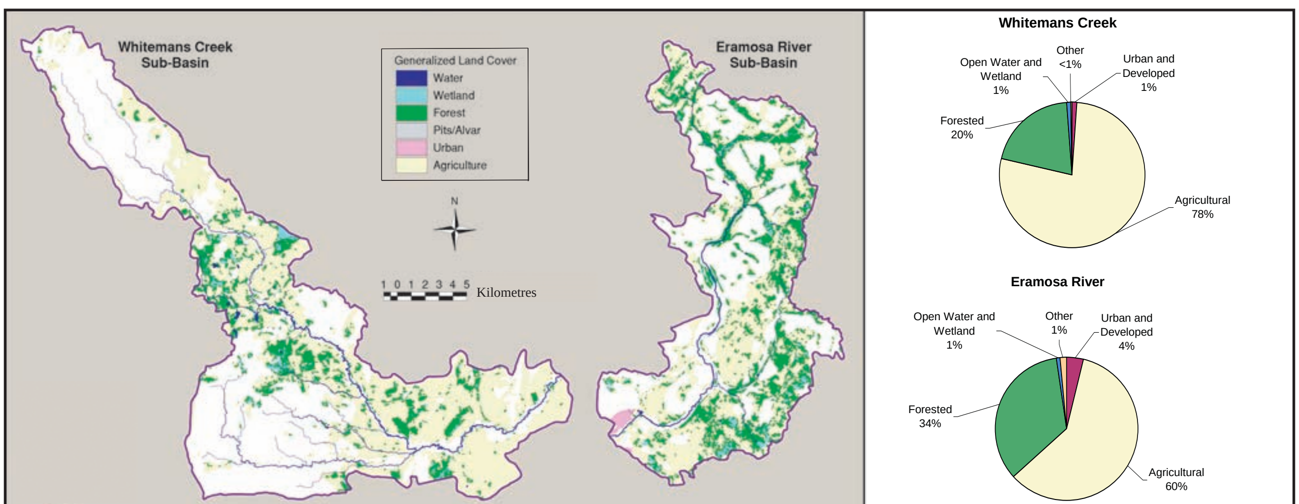

Figure 4. Land cover on moraine systems and areas that facilitate high to very high groundwater recharge of the Whitemans Creek and Eramosa River sub-watersheds: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority

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.

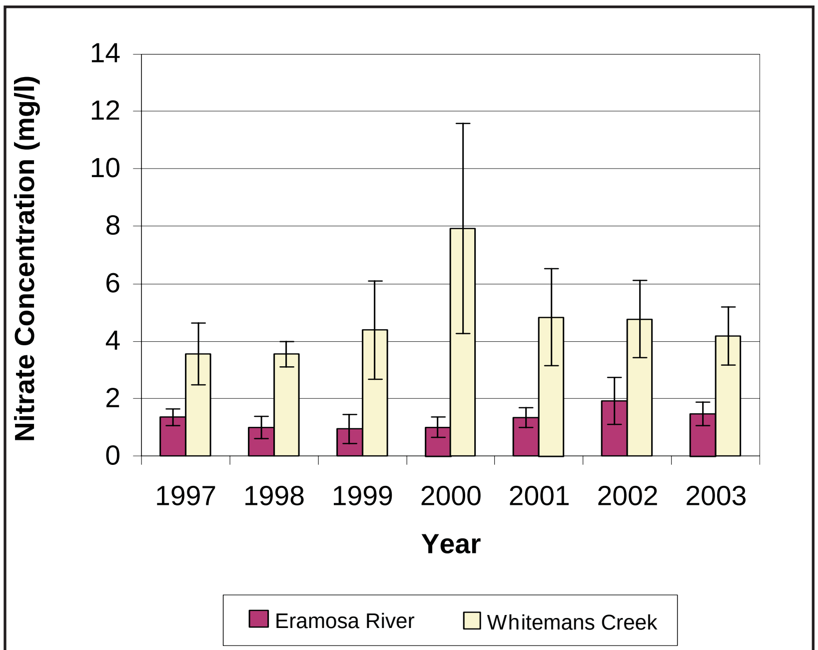

Figure 5. Average annual concentrations of nitrate measured in the Eramosa River and Whitemans Creek from 1997 to 2003. (Also shown on the bar graphs is the standard error of measurement)
Source: Ontario Provincial Water Quality Monitoring Network, 2003.

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.

Acknowledgments

Authors: Alan Sawyer, Grand River Conservation Authority, Cambridge, ON;
Sandra Cooke, Grand River Conservation Authority, Cambridge, ON;
Jeff Pitcher, Grand River Conservation Authority, Cambridge, ON; and
Pat Lapcevic, Grand River Conservation Authority, Cambridge, ON.

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Sources

Braun Consulting Engineers, Gartner Lee Limited, and

Jagger Hims Limited Consulting Engineers. 1999. *City of Guelph Water System Study Resource Evaluation Summary.* Report prepared for the City of Guelph.

Crowe, A.S., Schaefer, K.A., Kohut, A., Shikaze, S.G., and Ptacek, C.J. 2003. *Groundwater quality.* Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Canadian Council of Ministers of the Environment (CCME), Linking Water Science to Policy Workshop Series. Report No. 2, 52pp.

Holysh, S., Pitcher, J., and Boyd, D. 2001. *Grand River regional groundwater study.* Grand River Conservation Authority, Cambridge, ON, 78pp+ appendices.

Ontario Provincial Water Quality Monitoring Network. 2003. Grand River Conservation Authority Water Quality Stations.

Region of Waterloo. Official Municipal Website. http://www.region.waterloo.on.ca.

Stanley Consulting. 1998. *Chloride Impact Assessment Parkway and Strasburg Creek Well Fields Final Report*. Prepared for the Regional Municipality of Waterloo.

Whiffin, R.B., and Rush, R.J. 1989. Development and demonstration of an integrated approach to aquifer remediation at an organic chemical plant. In *Proceedings of the FOCUS Conference on Eastern Regional Ground Water Issues*, October 17-19, 1989, Kitchener, ON, Canada, pp. 273-288.

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.

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

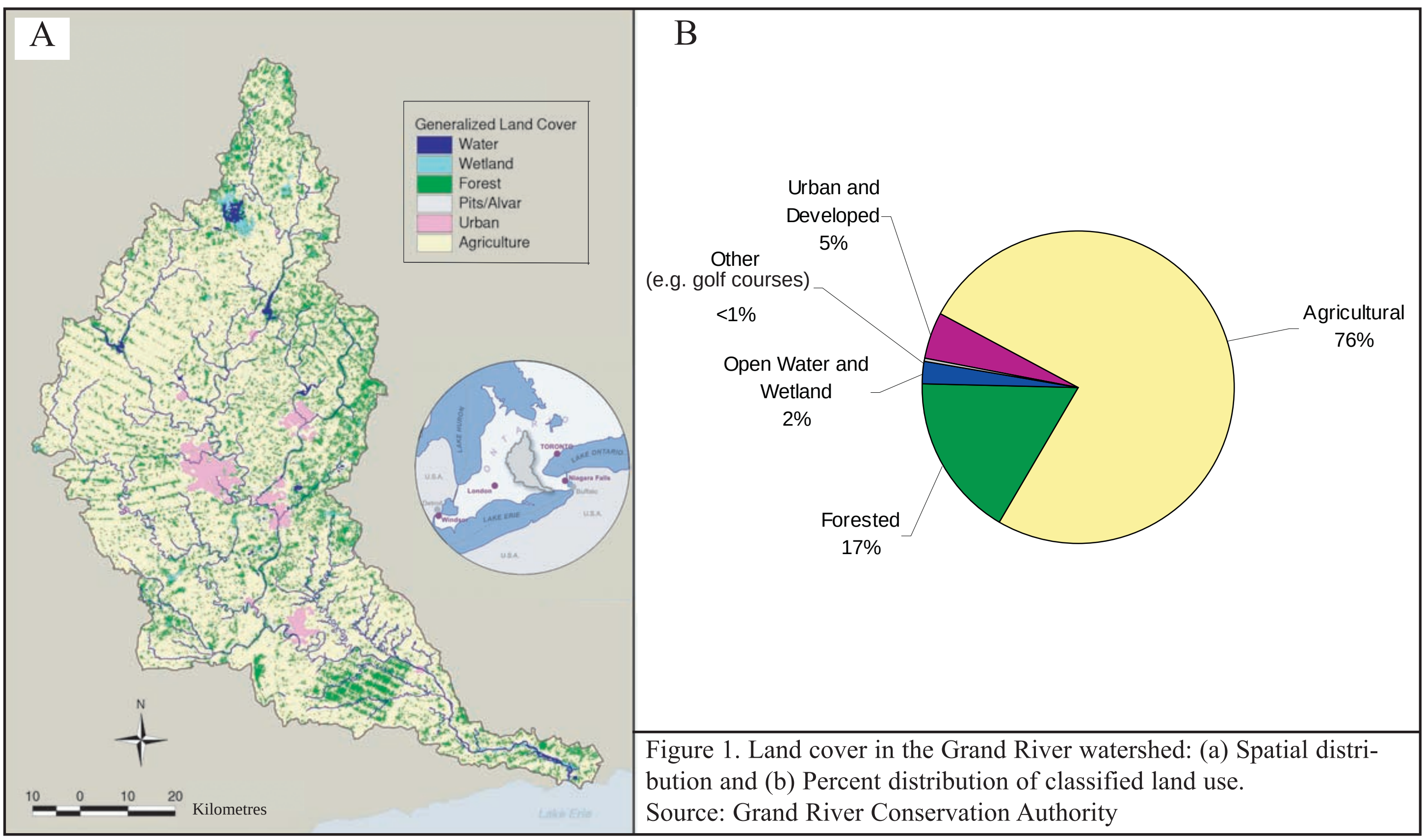


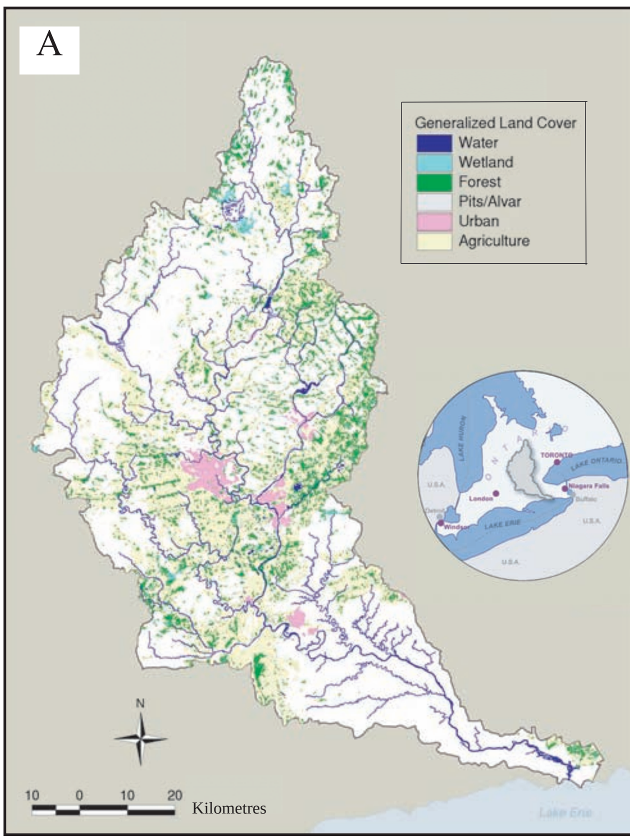
Figure 1. Land cover in the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority

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.



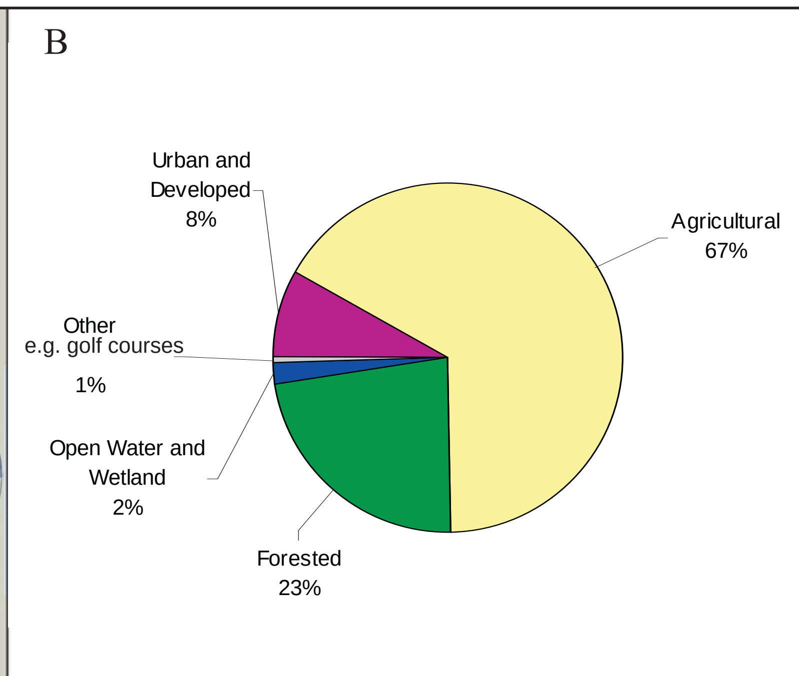


Figure 2. Land cover on moraine systems and areas that facilitate high or very high groundwater recharge of the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use. Source: Grand River Conservation Authority

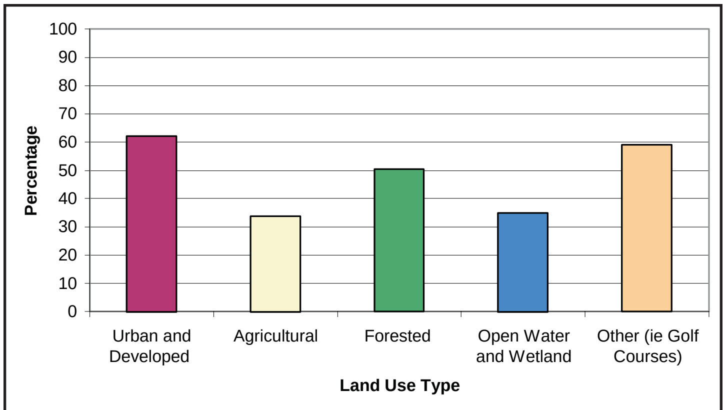


Figure 3. Percentage of land use type in significant recharge areas in the Grand River watershed.
Source: Grand River Conservation Authority

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

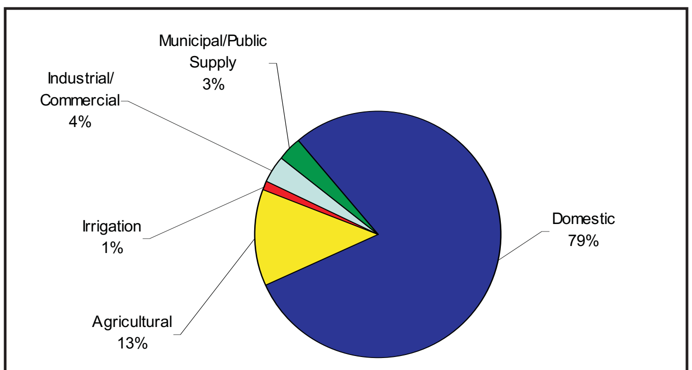


Figure 4. Distribution of groundwater wells by primary use in the Grand River watershed.
Source: Ontario Ministry of the Environment Water Well Database, 2003

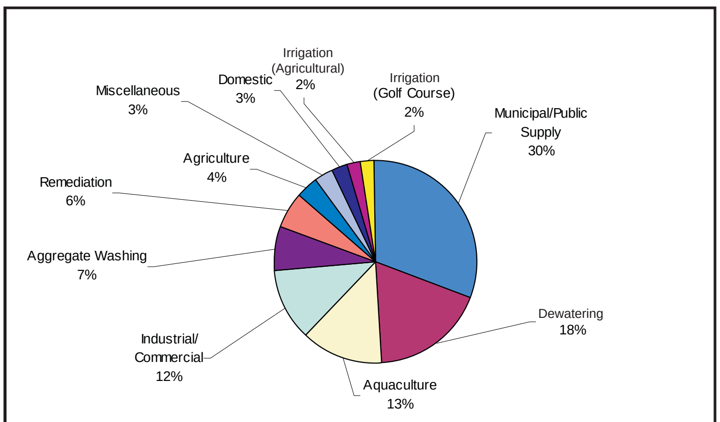


Figure 5. Percentage of total annual groundwater takings in the Grand River watershed from designated uses.
Source: Modified from Bellamy and Boyd, 2004

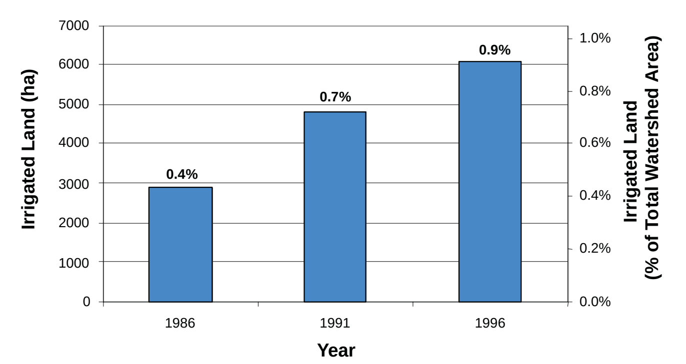


Figure 6. Changes in amount of irrigated land in the Grand River watershed (percentage of total watershed area irrigated). Source: Statistics Canada data for 1986, 1991, and 1996

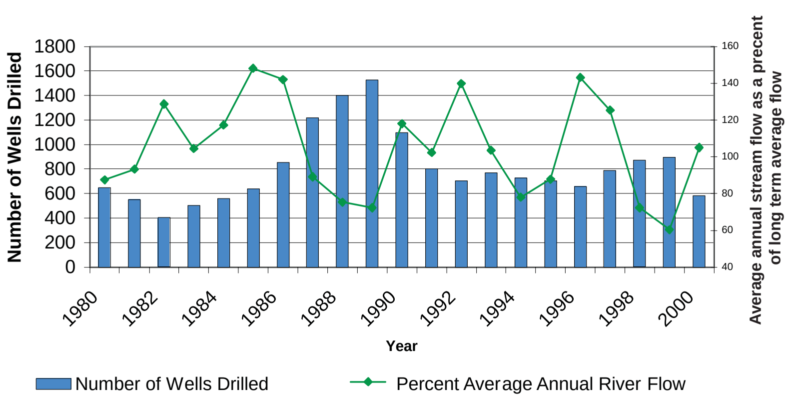


Figure 7. Number of new wells drilled each year (bars). Annual average stream flow (as a percentage on long term average) in the Grand River watershed illustrating below average, and average climatic conditions (green line).
Source: Ontario Ministry of the Environment Water Well Database, 2003

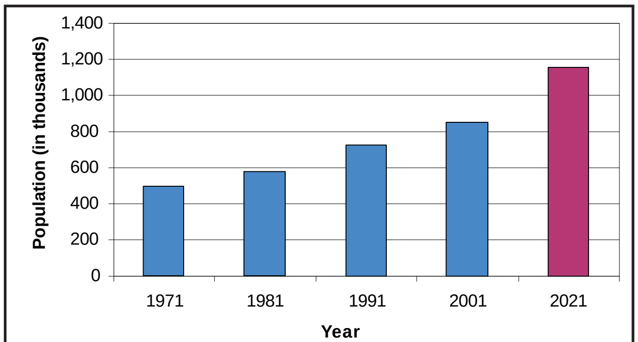


Figure 8. Estimated population in the Grand River watershed including future projections (burgundy bar).
Source: Dorfman, 1997 and Grand River Conservation Authority, 2003

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.

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.

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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Sources

Bellamy, S., and Boyd, D. 2004. *Water use in the Grand River watershed.* Grand River Conservation Authority, Cambridge, ON.

Dorfman, M.L., and Planner Inc. 1997. *Grand River Watershed Profile.* Prepared for the Grand River Conservation Authority.

Grand River Conservation Authority (GRCA). 2003. *Watershed Report.* Grand River Conservation Authority, Cambridge, ON.

Holysh, S., Pitcher, J., and Boyd, D. 2001. *Grand River Regional Groundwater Study.* Grand River Conservation Authority, Cambridge, ON.

Ontario Ministry of the Environment. 2003. *Water Well Information System Database*. Ministry of Environment, Toronto, ON.

Region of Waterloo. Official Municipal Website. http://www.region.waterloo.on.ca

Statistics Canada. Census of Agriculture. 1986, 1991, 1996. Statistics Canada, Ottawa, ON.

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.

Base Flow Due to Groundwater Discharge

Indicator #7102

Assessment: Mixed, Deteriorating

Note: Additional analyses and interpretation are required to validate this tentative assessment. This assessment is based on the examples of analysis and interpretation that are described in this report and the perception of water resource specialists that, in at least some settings, base flow due to groundwater discharge has been impacted by factors such as urban development and water use.

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. All groundwater discharge contributes to base flow but not all base flow is the result of groundwater discharge.

Status of Base Flow

Information that is required to assess base flow due to groundwater discharge at the scale of the Great Lakes basin in terms of present conditions and trends is currently being assembled. This report summarizes the importance of base flow due to groundwater discharge in the context of the Great Lakes ecosystem and provides examples of the analysis and interpretation of base flow information. More detailed presentation of these and additional results will be feasible for the 2006 reporting period.

Base flow is frequently determined using a mathematical process known as base flow 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. Figure 1 illustrates daily stream flow monitoring information and the results of base flow separation for the Nith River near Canning, Ontario for January 1 to December 31, 1999. The rapidly varying response of stream flow to precipitation and snow melt during the winter, early spring, and late fall are in contrast to the more slowly varying base flow, which is the shaded portion of the hydrograph shown in Figure 1.

Application of base flow 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 and physical metric 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 aver-

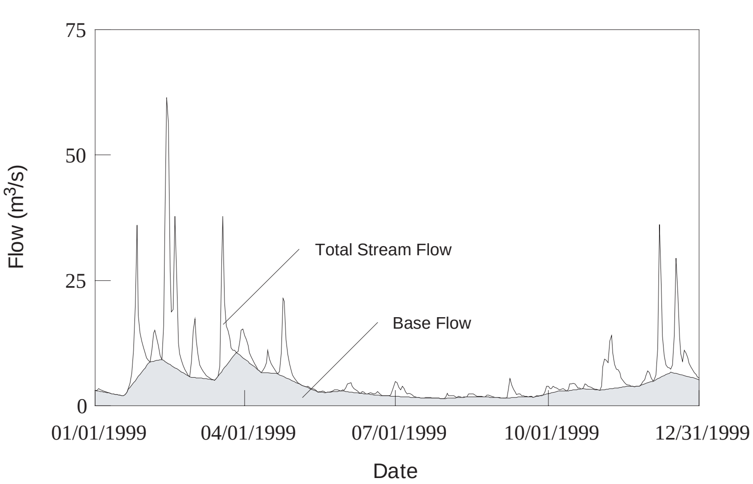

Figure 1. Hydrograph of observed total stream flow and calculated base flow for the Nith River near Canning during 1999.
Source: Environment Canada and the U.S. Geological Survey

age rate of base flow relative to the average rate of total stream flow 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 0.62, which implies that 62% of the observed flow is estimated to be base flow.

The USGS and Environment Canada's National Water Research Institute are calculating base flow using stream flow monitoring information for all gauges in Ontario and the eight Great Lakes states. Early results, summarized in terms of base flow index and plotted relative to the locations of the gauges, are shown in Figure 2. Results have also been calculated for Quebec and are plotted in Figure 2. These results are unfiltered and are known to reflect factors such as flow regulation and extensive areas of lakes and wetlands that modify the observed stream flow regimes. The results are, therefore, not yet a certain indicator of groundwater conditions, particularly in the regions of Ontario and Quebec where lakes and wetlands are most abundant. Figure 2 also illustrates the results of averaging the values of base flow index calculated for the gauges over the United States and Canadian sub-sub-basins and sub-basins of the Great Lakes (GLIN 2000).

The diversity of groundwater conditions within the Great Lakes basin is apparent in Figure 2. For example, lower values of base flow index that occur in southwestern Ontario are similar to those in eastern Michigan and to even lower values that occur along the southern shore of Lake Erie. A region of lower values also occurs in eastern Ontario where the geology is similar to that of southwestern Ontario. Water management practices that are successful in southwestern Ontario may, therefore, be more relevant in eastern Ontario than in central Ontario where intermediate values of base flow index are typical. Further analysis is required to determine if the lower values of base flow index that occur along the western and southern shore of Lake Michigan are the result of geologic factors, urban development, or the intensive use of groundwater. The higher values of base flow

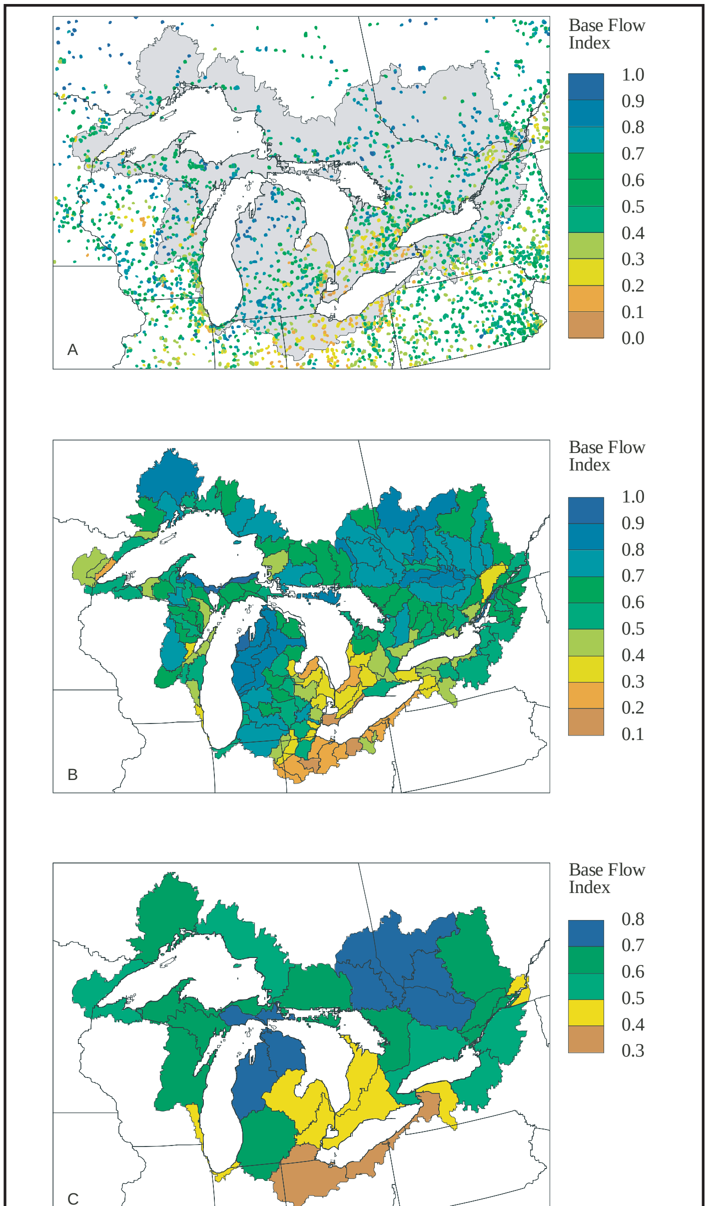

Figure 2. Values of base flow index calculated for stream flow gauges in Ontario, Quebec, and the eight Great Lakes states (A) and these values averaged over the corresponding sub-sub-basins (B) and sub-basins (C) of the Great Lakes and Ottawa River. Different legends are used for each set of results in order to most clearly depict the range of values of base flow index.
Source: Environment Canada and the U.S. Geological Survey

index that occur in northern Michigan appear to be unique as the comparable values that occur within the Ottawa River drainage basin may be a reflection of the abundance of lakes and wetlands. The glacial deposits in the northern part of Michigan's Lower Peninsula are dominantly composed of sand and gravel with high rates of infiltration.

Base flow information can also be used to detect changes in stream flow regimes and, therefore, to assess the impacts of various human and climatic factors. This is demonstrated through the interpretation of information for stream flow gauge 02GA003 on the Grand River at Galt, Ontario; gauge 02GA010 on the Nith River near Canning, Ontario; and gauge 04166100 on the River Rouge at Southfield, Michigan. The locations, watersheds, and surface water features of these gauges are shown in Figure 3. The most lightly shaded areas in Figure 3 denote relatively intense nighttime lighting due to human settlements (NOAA DMSP 2002), which is an indicator of urban development. The extent of nighttime lighting ranges from very limited within the watershed of the Nith River to modest within the watershed of the Grand River and intense throughout the watershed of the River Rouge.

Figure 3. Locations of the Grand River at Galt (02GA003), Nith River near Canning (02GA010), and River Rouge at Southfield (04166100). The locations of the three stream flow gauges are indicated by red points and the corresponding watersheds are most darkly shaded. Areas of nighttime lighting are more lightly shaded.
Source: Environment Canada and the U.S. Geological Survey

Stream flow in the Grand River at Galt is regulated by eight dams and reservoirs. These structures are used to retain a portion of stream flow during periods of high flow and release water from storage during periods of low flow. The structures are, therefore, multi-purpose in that they reduce the potential for flooding and maintain water quantity and quality during periods of low flow. The dams were constructed from 1942 to 1978 and control reservoirs with a combined storage capacity of 187 million cubic metres, which is equivalent to the average stream flow in the Grand River at Galt for 60 days. There are no major flow regulation structures upstream of the Nith River near Canning, and very limited urban development, and the observed stream flow regime is, therefore, believed to be near-natural.

Annual values of base flow index calculated for the Grand River at Galt and Nith River near Canning are illustrated in Figure 4. The dates of construction and cumulative capacities of the flow regulation structures are plotted relative to the results for the Grand River at Galt. The largest of the structures – the Shand, Luther, Conestogo, and Guelph dams – were constructed in 1942, 1952, 1958, and 1976, respectively. The impact of the construction of the dams, particularly of the Conestogo dam, on the stream flow regime is significant. The average of the annual values of base flow index for years prior to the construction of the first of the dams in 1942 is 0.44 and the average for years following the construction of the final dam in 1978 is 0.59. Flow regulation has, therefore, resulted in an increase in base flow index of 0.15. Annual values of base flow index calculated for the Nith River near Canning do not follow the same trend. The averages of the values prior to 1942 and following 1978 are both equal to 0.49. In addition, while only roughly 10% of the values of base flow index calculated for the Grand River at Galt following the construction of the Conestogo dam are less than average, roughly 60% of the values calculated for the Nith River near Canning during the same period are below average.

Interpretation of base flow information for the River Rouge at Southfield is more complex. Significant population growth in Oakland County, which includes the watershed for the River Rouge, began between 1910 and 1920 and was greatest between roughly 1940 and 1970. Annual values of base flow index for the River Rouge at Southfield from 1959 to 2000 are illustrated in Figure 5 and compared to annual precipitation and statistics of the observed stream flow. The stream flow statistics are the minimum and maximum of the daily values for each year and the average of the daily values. Precipitation and base flow index alternate between below and above average and do not indicate a clear trend. Roughly 50% of the values of base flow index are below average and roughly 50% of the values are above average. Base flow index is below average most frequently when precipitation is above average and likewise is above average most frequently when precipitation is below average. Year-to-year variations in base flow index are, therefore, at least partly controlled by climate with the expected outcome of higher rates of base flow relative to total stream flow in drier years.

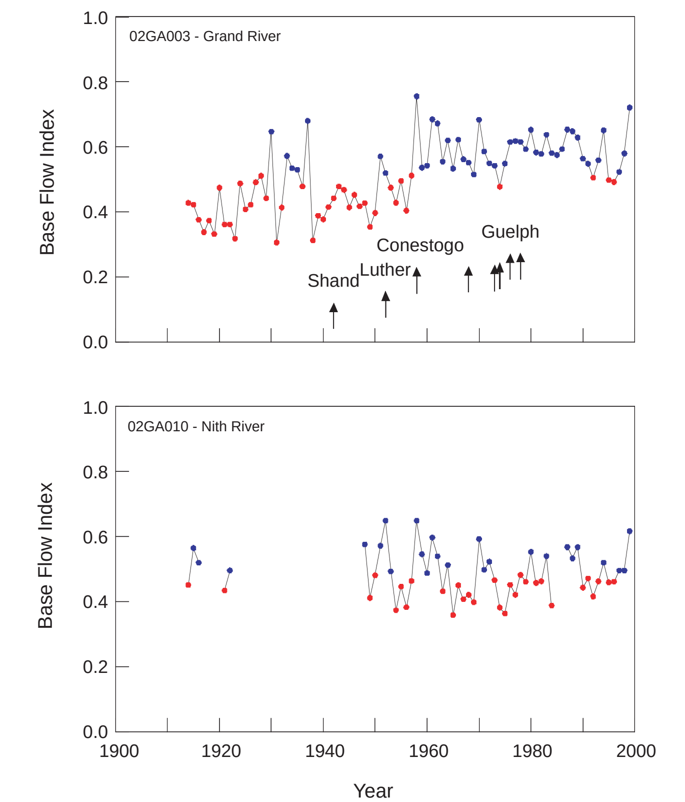

Figure 4. Annual values of base flow index for the Grand River at Galt (02GA003) and Nith River near Canning (02GA010). The red and blue points indicate annual values that are below and above, respectively, the average of all of the values for each gauge. Arrows indicate the years that dams/reservoirs were constructed.
Source: Environment Canada and the U.S. Geological Survey

The maximum values of flow in the River Rouge alternate between below and above average over the duration of the data. In contrast, the average and minimum values of flow appear to indicate a change in the flow regime that may be related to the urbanization of the watershed. A reduction in the year-to-year variation of both statistics is apparent beginning in approximately 1972. During the 12 years of 1989 to 2000, precipitation was below average during eight years while average stream flow was below average during only one year and minimum stream flow was never below average. Episodes of very low flow, minimum values approaching zero, were common during the period of 1961 to 1971 and did not re-occur after 1971. It is likely that these changes in the stream flow regime are due to conveyance losses and other discharges of municipally supplied water taken from sources outside of the watershed.

The annual values of base flow index calculated for the River Rouge at Southfield do not appear to indicate the effects of urbanization of the watershed. It is generally assumed that urbanization results in increased extents of impervious surfaces such as pavement and roofing, more rapid drainage, and a corresponding decrease in the base flow component of stream flow. It

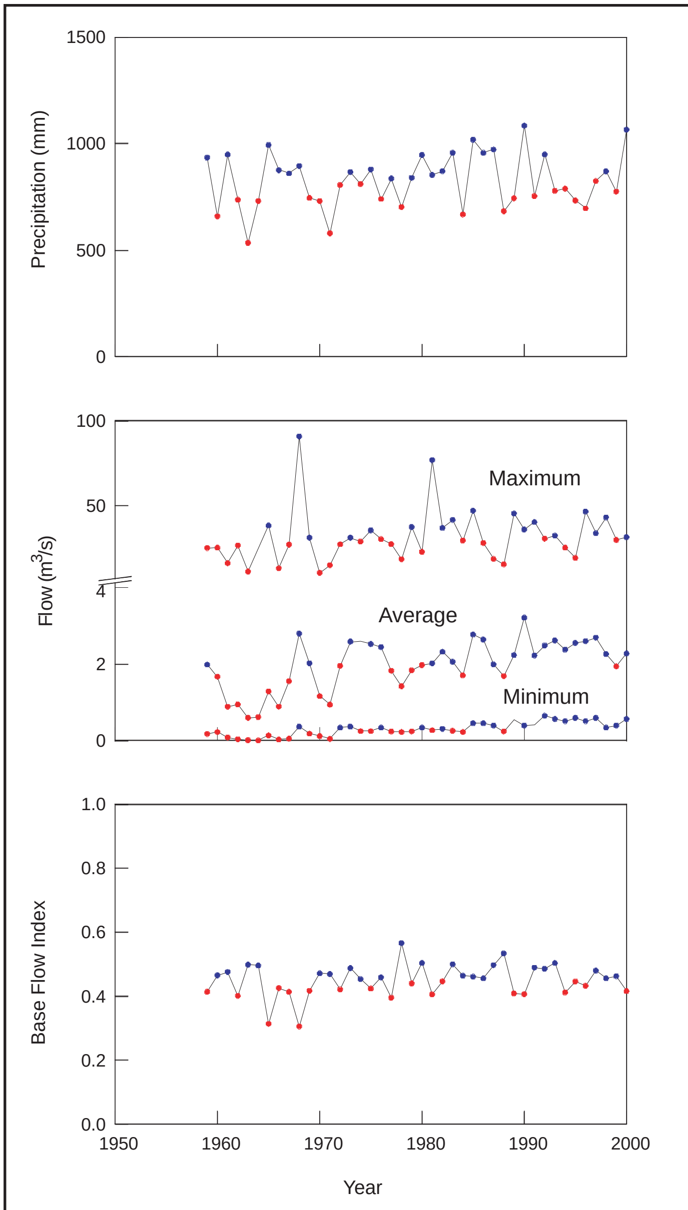

Figure 5. Annual values of total precipitation; annual values of the minimum, maximum, and aver age of daily stream flow; and annual values of base flow index for the River Rouge at Southfield. The red and blue points indicate annual values that are below and above, respectively, the average of all of the values of each parameter.
Source: Environment Canada and the U.S. Geological Survey

is possible that, in this case, the anticipated reduction in base flow index is offset by an increase resulting from discharges of municipally supplied water. Additional analyses of near-natural and urbanized watersheds are required to determine if these findings are typical or anomalous. It is important to note that, while base flow index does not appear to respond to the urbanization of the watershed, the apparent increase in average flow multiplied by the nearly constant value of base flow index does imply an increase in annual volumes of base flow.

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. 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 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. Results, such as those shown in Figure 2 of 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 diversity 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 remediation of contamination, in general, and non-point source contamination, in particular.

Acknowledgments

Authors: Andrew Piggott, National Water Research Institute, Environment Canada;
Sarah Day, National Water Research Institute, Environment Canada;
Brian Neff, U.S. Geological Survey; and
Jim Nicholas, U.S. Geological Survey.

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Sources

Great Lakes Information Network (GLIN). 2000. *Basin wide reference layers, Great Lakes region watersheds*. http://www.glin.net/gis/data/refdata/glwsheds.zip.

National Oceanic and Atmospheric Administration, Defense Meteorological Satellite Program (NOAA DMSP). 2002. *Nighttime lights of the world: 1994-1995, Human settlements.* http://dmsp.ngdc.noaa.gov/data/stable_lights/cities.tar.

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).

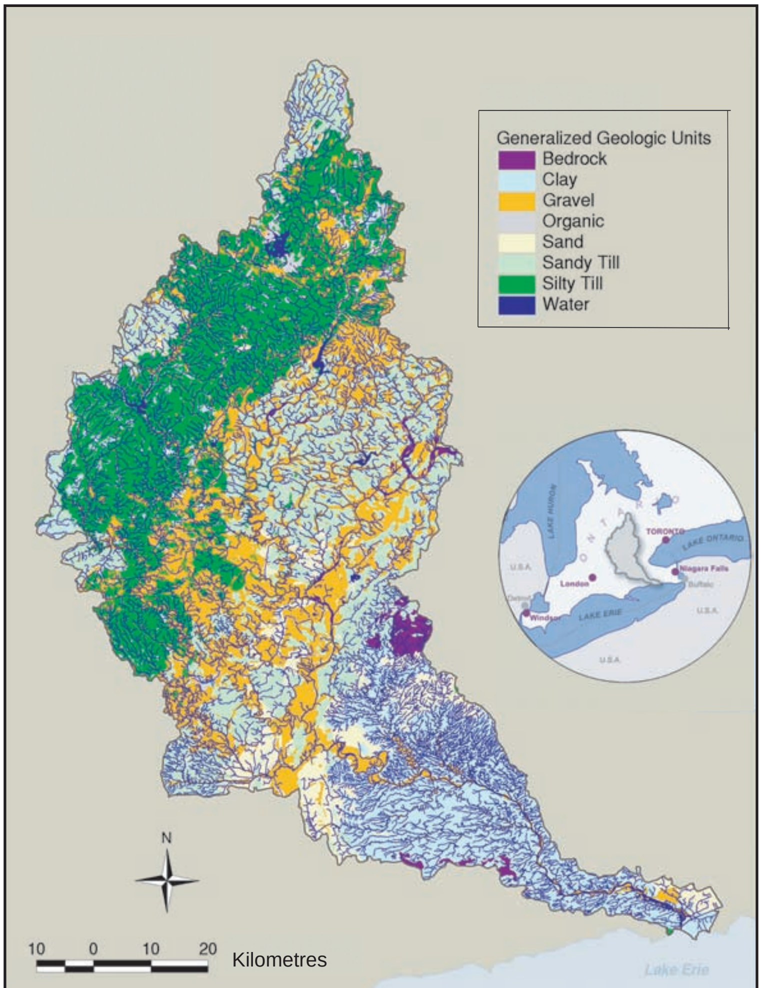

Figure 1. Surficial geology of the Grand River watershed.
Source: Grand River Conservation Authority

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.

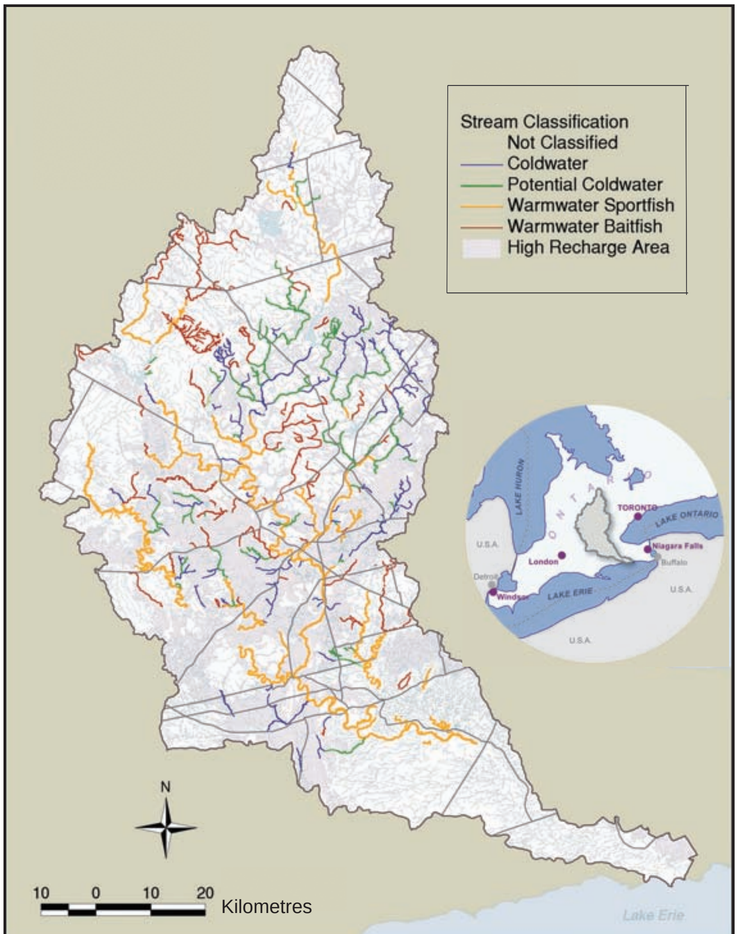

Figure 2. Streams of the Grand River watershed.
Source: Grand River Conservation Authority

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.

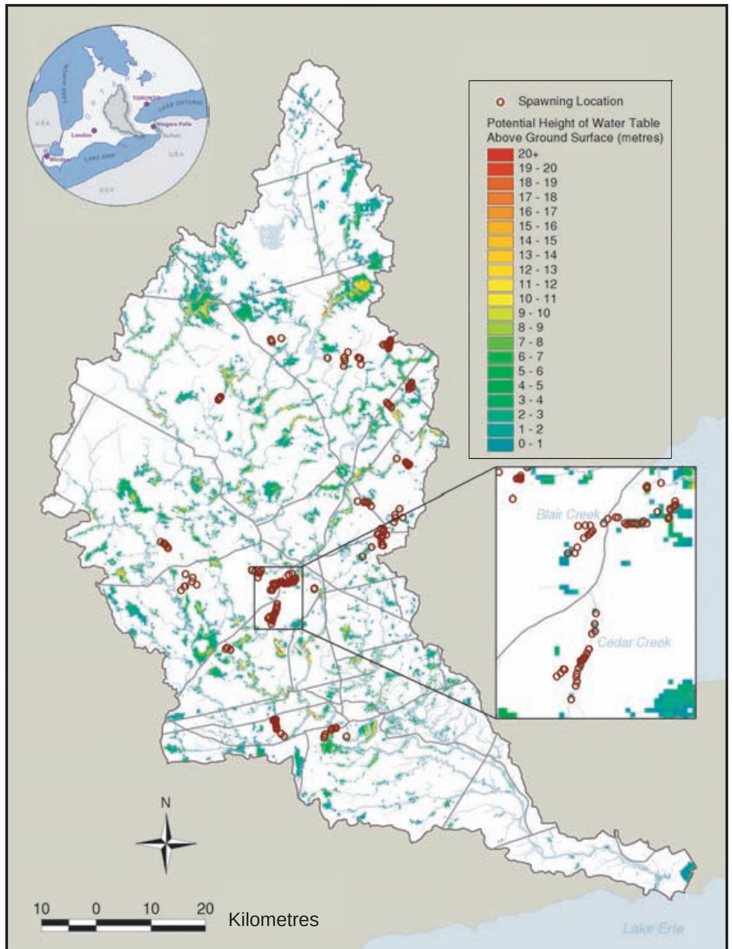

Figure 3. Map of potential discharge areas in the Grand River watershed.
Source: Grand River Conservation Authority

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.

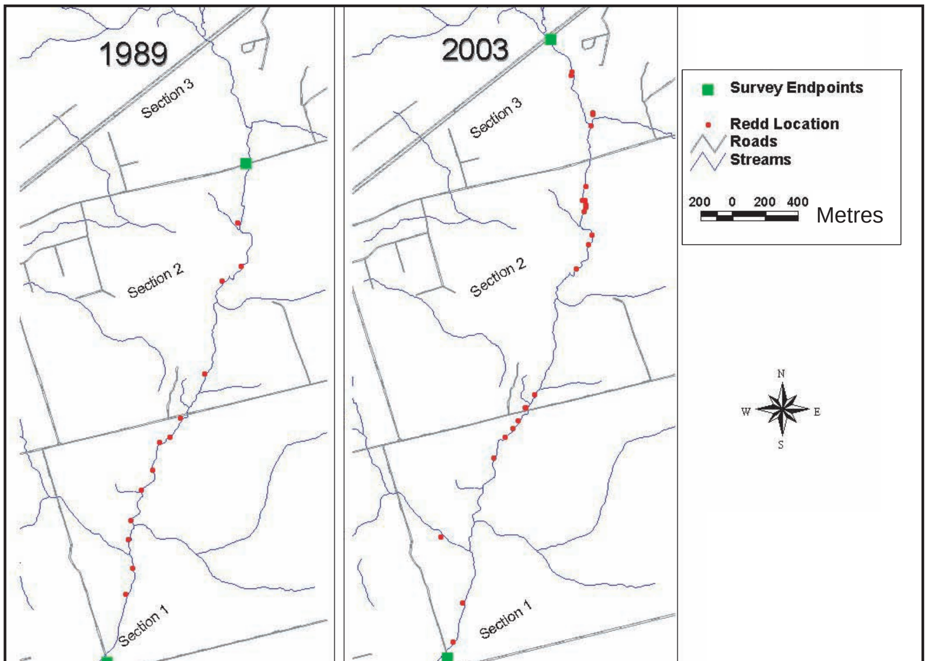

Figure 4. Results of brook trout spawning surveys carried out in the Cedar Creek subwatershed in 1989 and 2003.
Source: Grand River Conservation Authority

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

Authors: Alan Sawyer, Grand River Conservation Authority, Cambridge, ON;
Sandra Cooke, Grand River Conservation Authority, Cambridge, ON;
Jeff Pitcher, Grand River Conservation Authority, Cambridge, ON; and
Pat Lapcevic, Grand River Conservation Authority, Cambridge, ON.

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Sources

Grand River Conservation Authority. 2003. Brook Trout *(Salvelinus fontinalis)* Spawning Survey – Cedar Creek.

Grillmayer, R.A., and Baldwin, R.J. 1990. *Salmonid spawning surveys of selected streams in the Grand River watershed 1988-1989.* Environmental Services Group, Grand River Conservation Authority.

Holysh, S., Pitcher, J., and Boyd, D. 2001. *Grand River Regional Groundwater Study.* Grand River Conservation Authority, Cambridge, ON. 78pp. + figures and appendices.

Scott, W.B., and Crossman, E.J. 1973. *Freshwater fishes of Canada*. Bulletin 184, pp. 208-213. Fisheries Research Board of Canada, Ottawa, ON.

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.

Area, Quality and Protection of Special Lakeshore Communities - Alvars

Indicator #8129 (Alvars)

This indicator report is from 2001.

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.

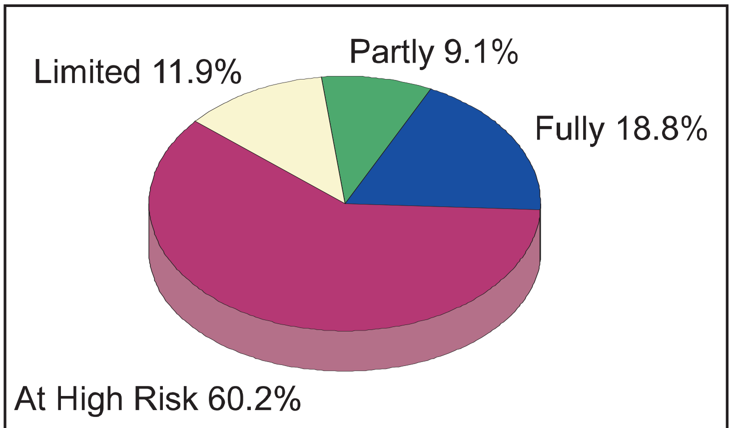

Figure 1. Protection status of nearshore alvar area (2000).
Source: Ron Reid, Bobolink Enterprises

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).

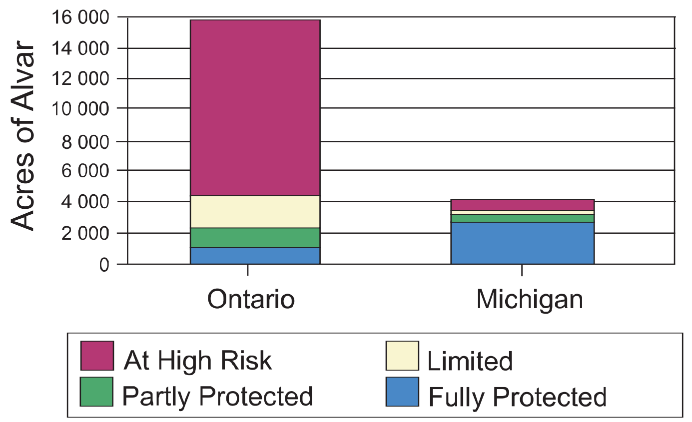

Figure 2. Comparison of the protection status of nearshore alvars (in acres) for Ontario and Michigan.
Source: Ron Reid, Bobolink Enterprises

Each location of an alvar community or rare species has been documented as an "element occurrence" or EO. Each alvar community 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.

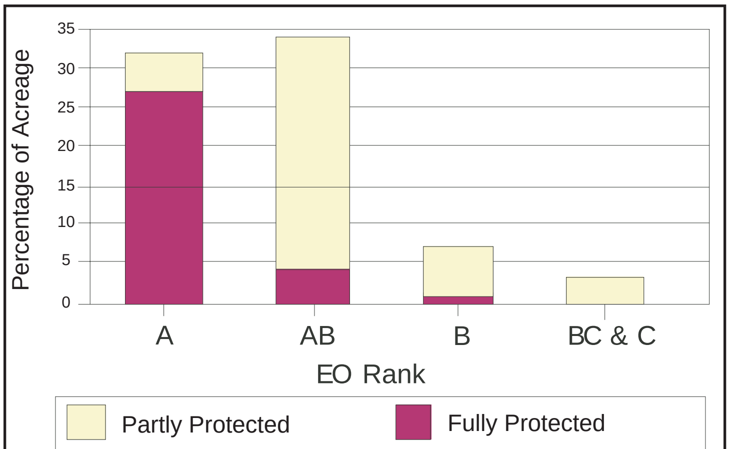

Figure 3. Protection of high quality alvars. EO Rank = Element Occurrence (A is excellent, B is good and C is marginal).
Source: Ron Reid, Bobolink Enterprises

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.

Sources

Brownell, V.R., and Riley, J.L. 2000. *The alvars of Ontario: significant alvar natural areas in the Ontario Great Lakes Region.* Federation of Ontario Naturalists, Toronto, ON.

Cusick, A.W. 1998. *Alvar landforms and plant communities in Ohio.* Ohio Department of Natural Resources, Columbus, OH.

Gilman, B. 1998. *Alvars of New York: A Site Summary Report*. Finger Lakes Community College, Canandaigua, NY.

Lee, Y.M., Scrimger, L.J., Albert, D.A., Penskar, M.R., Comer, P.J., and Cuthrell, D.A. 1998. *Alvars of Michigan.* Michigan Natural Features Inventory, Lansing, MI.

Reid, R. 2000. *Great Lakes alvar update, July 2000*. Prepared for the International Alvar Conservation Initiative Working Group. Bobolink Enterprises, Washago, ON.

Reschke, C., Reid, R., Jones, J., Feeney, T., and Potter, H. 1999. *Conserving Great Lakes alvars: final technical report of the International Alvar Conservation Initiative*. The Nature Conservancy, Chicago, IL.

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.

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

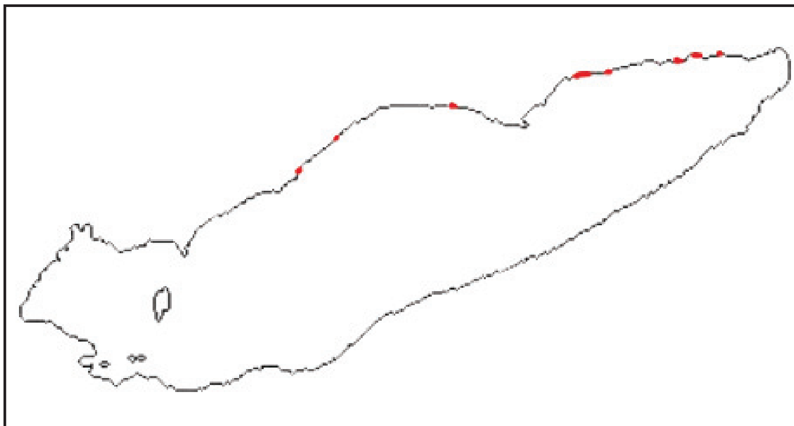

Figure 5. Cobble beaches along Lake Erie's shoreline (red = cobble beach locations).
Source: Environment Canada

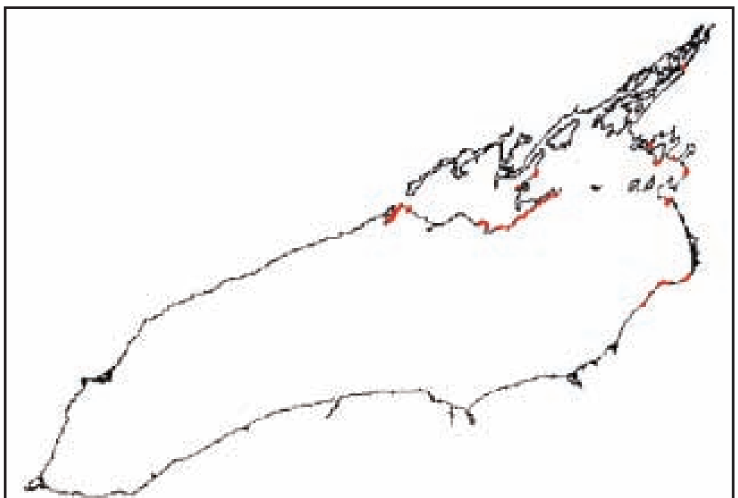

Figure 4. Cobble beaches along Lake Ontario's shoreline (red = cobble beach locations).
Source: International Joint Commission (IJC) and Christian J. Stewart

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.

Sources
Albert, D. 1994a. *Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: a working map and classification.* Michigan Natural Features Inventory, Lansing, MI.

Albert, D., Comer, P., Cuthrell, D., Penskar, M., Rabe, M., and Reschke, C. 1994b. *Bedrock shoreline surveys of the Keweenaw Peninsula and Drummond Island in Michigan's Upper Peninsula*. Michigan Natural Features Inventory, Lansing, MI.

Albert, D.A., Comer, P.J., Corner, R.A., Cuthrell, D., Penskar, M., and Rabe, M. 1995. *Bedrock shoreline survey of the Niagaran escarpment in Michigan's Upper Peninsula: Mackinac County to Delta County.* Michigan Natural Features Inventory, Lansing, MI.

Environment Canada. 1994a. *Environmental Sensitivity Atlas for Lake Erie (including the Welland Canal) and the Niagara River shorelines*. Environment Canada, Ontario Region, United States Coast Guard, and the United States National Oceanic and Atmospheric Administration (NOAA).

Environment Canada. 1994b. *Environmental Sensitivity Atlas for Lake Huron's Canadian shoreline (including Georgian Bay).* Environment Canada, Ontario Region.

Humphrys, C.R., Horner, R.N., and Rogers, J.H. 1958. *Shoretype Bulletin Nos. 1-29*. Michigan State University Department of Resource Development, East Lansing, MI.

International Joint Commission (IJC) 2002. *Classification of shore units. Coastal working group. Lake Ontario and Upper St. Lawrence River.* Environment Canada and U.S. Environmental Protection Agency (USEPA).

Lake Superior Binational Program. 2000. *Lake Superior Lakewide Management Plan (LaMP) 2000.* Environment Canada and U.S. Environmental Protection Agency (USEPA).

Michigan's Natural Features Inventory (MNFI). *Rare Plant Reference Guide*. Michigan State University Extension. http://web4.msue.msu.edu/mnfi/data/rareplants.cfm, last accessed October 5, 2005.

Stewart, C.J. 2003. *A revised geomorphic, shore protection and nearshore classification of the Canadian and United States shorelines of Lake Ontario and the St. Lawrence River*. Christian J. Stewart Consulting, British Columbia, Canada.

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.

Area, Quality, and Protection of Special Lakeshore Communities - Islands
Indicator #8129 (Islands)

Note: This is a progress report towards implementing this indicator.

Assessment: Not Assessed
Indicator is under development. Data are not available.

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 over thirty thousand islands in the Great Lakes. 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 (Figure 1).

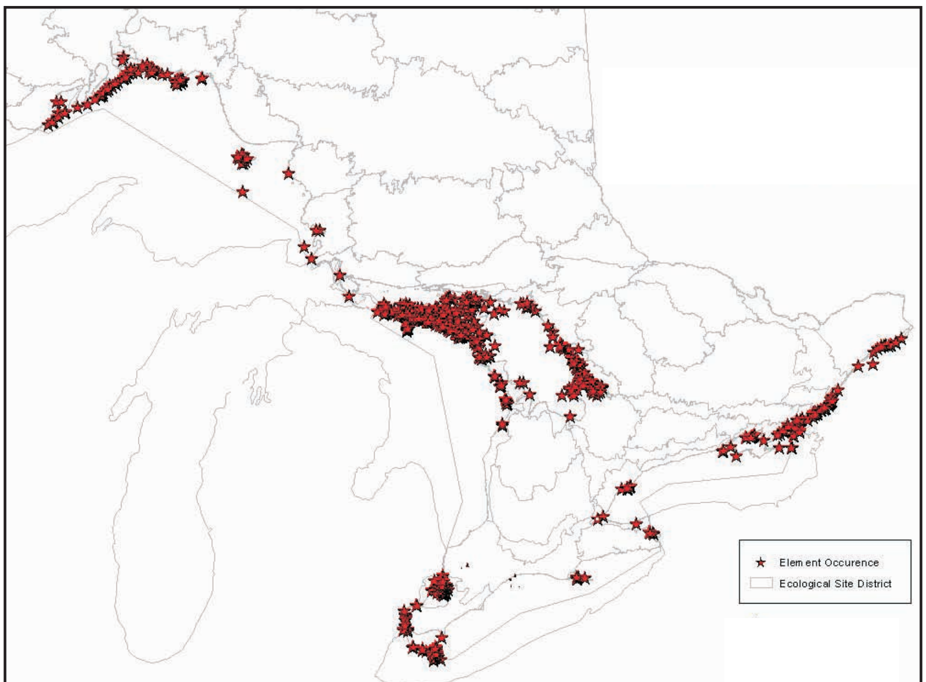

Figure 1. Distribution of Ontario's provincially rare species and vegetation communities on islands in the Great Lakes.
Source: Ontario Natural Heritage Information Centre, March 2003

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 devel-

opment, 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.

Acknowledgments
Authors: Richard H. Greenwood, U.S. Fish and Wildlife Service, Great Lakes Basin Ecosystem Team Leader and Liaison to U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL;
Dr. Karen E. Vigmostad, Great Lakes Policy Analyst Ecosystem Team, Northeast-Midwest Institute, Washington, DC;
Megan M. Seymour, Wildlife Biologist, U.S. Fish and Wildlife Service, Great Lakes Basin Ecosystem Team Island Committee Chair, Ecological Services Field Office, Reynoldsburg, OH;
Dr. Francesca Cuthbert, Dept. of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, St. Paul, MN;
Dr. David Ewert, Director of Conservation Science, Great Lakes Program, Nature Conservancy, Lansing, MI;
Dan Kraus, Coordinator of Conservation Science, Ontario Region of Nature Conservancy of Canada, Guelph, ON; and
Linda R. Wires, Research Associate, Dept. of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, St. Paul, MN.

Sources
Susan Crispin, Director, Montana Natural Heritage Program, Helena, MT. Ph: 406-444-5434, scrispin@state.mt.us.

Bruce Manny and Greg Kennedy, U.S. Geological Survey, Great Lakes Science Center, 1451 Green Road Ann Arbor, MI 48105-2807. Ph: 734-214-7213, bruce_manny@usgs.gov or gregory_kennedy@usgs.gov.

Dr. Judy Soulé, Director, U.S. Network Partnerships, Nature Serve, East Lansing, MI. Ph: 517-381-5310, judy_soule@natureserve.org.

Dr. Karen E. Vigmostad, Great Lakes Policy Analyst, Northeast-Midwest Institute, Washington, DC. 20003. Ph: 202-464-4016, kvigmostad@nemw.org.

Authors' Commentary
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, lead by Dr. Karen Vigmostad of the Northeast-Midwest Institute. 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 is developing:
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.

A proposed second year of GLNPO funding would allow the Collaborative to complete a threats assessment, identify island biodiversity investment areas, publish an atlas of the biodiversity of Great Lakes Islands, complete an island policy assessment, distribute a draft Great Lakes Islands Conservation Action plan, and develop an e-resource library on islands.

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.

Area, Quality and Protection of Special Lakeshore Communities - Sand Dunes

Indicator #8129 (Sand Dunes)

Note: This is a progress report towards implementing this indicator.

Assessment: Not Assessed

Purpose

- To assess the extent and quality of Great Lakes sand dunes, one of the 12 special lakeshore communities identified within the nearshore terrestrial area.

Ecosystem Objective

Maintain total areal extent and quality of Great Lakes sand dunes, ensuring adequate representation of sand dune types across their historical range.

State of the Ecosystem

Sand dunes continue to be lost and degraded, yet the ability to track and determine the extent and rate of this loss in terms of both area and quality in a standardized way is not yet feasible.

Great Lakes sand dunes comprise the world's largest collection of freshwater dunes. They are home to endemic, rare, endangered, and threatened species. Sand dunes can be found along the coasts of all the Great Lakes. Lake Michigan, however, has the greatest number of sand dunes with a total of 111,291 hectares, followed by Ontario with 8,910 hectares, Indiana with 6,070 hectares, New York with 4,850 hectares, and Wisconsin with 425 hectares. This information is not complete. No comprehensive map of Great Lakes sand dunes exists – although some work has taken place in Ontario for each lake basin.

Degree of protection varies considerably among jurisdictions so it is difficult to assess the overall loss or status of sand dunes because although information about the quality of individual sand dunes is locally available, this information has not been collected across the entire basin. Nevertheless, conversations with local managers and environmentalists indicate a continued loss of sand dunes to development, sand mining, recreational trampling, and non-indigenous invasive species. The Lake Ontario Dunes Coalition, Michigan Dunes Alliance, and the Save the Dunes Council in Indiana are making some progress in both protecting and restoring sand dunes in their respective regions.

Pressures

Threats to sand dunes are numerous. Non-indigenous invasive species such as baby's breath (*Gypsophila paniculata*) and spotted knapweed (*Centaurea maculosa*) tend to spread rapidly if not controlled. Habitat destruction, however, is the greatest threat. In addition to sand mining, shoreline condominium and second home development level the dunes. Recreational use by pedestrians and off road vehicle use destroys vegetation, thereby causing dune erosion.

Management Implications

Many actions have been taken to protect Great Lakes sand dunes. For example, in Eastern Lake Ontario boardwalks and dune walkovers have been constructed to provide public access to beaches without compromising dune ecology. Native beach grasses have been planted to retard erosion. On the eastern shores of Lake Michigan, invasive plants have been systematically removed by dune stewards. Michigan has legislation in place to control or reduce sand mining impacts.

In order to protect sand dunes there is a need for improved communication between government agencies and stakeholders with regard to sand dune management. Public education would help alleviate stress to dunes cause by recreational trampling. Stronger legislation could limit some damaging activities. Local government creativity in managing dune areas through creative zoning would improve the protection of sensitive and irreplaceable areas.

Acknowledgments

Author: Lindsay Silk, Environment Canada, Downsview, ON.

Sources

Bonanno, S. 1998. The Nature Conservancy.

Byrne, M.L. 2004. Personal communication.

Cabala, T. 2004. Personal communication.

Environment Canada and the U.S. Environmental Protection Agency. 1997. *State of the Great Lakes 1997*.

Lewis, J. 1975. Michigan Geological Survey Division Circular (#11). http://www.geo.msu.edu/geo333/sand.html, last accessed April 6, 2004.

Michigan Department of Environmental Quality. 2004. http://www.michigan.gov/deq/0,1607,7-135-3311_4114_4235—,00.html, last accessed April 6, 2004.

U.S. Environmental Protection Agency (USEPA). 2002. Protecting and Restoring Great Lakes Sand Dunes. http://www.epa.gov/owow/estuaries/coastlines/dec02/sand_dunes.html, last accessed March 29, 2004.

Authors' Commentary
A group of sand dune managers and scientists is organizing a conference for all persons involved in Great Lakes sand dune ecosystem ecology, management, research and education efforts. The purposes of the conference will be to compile information about sand dunes and sand dune research and management and to form the Great Lakes Sand Dunes Coalition. This group could work actively to collect available data about Great Lakes sand dunes and begin collaborative actions to protect them.

Extent of Hardened Shoreline

Indicator #8131

This indicator report is from 2001.

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 develop-

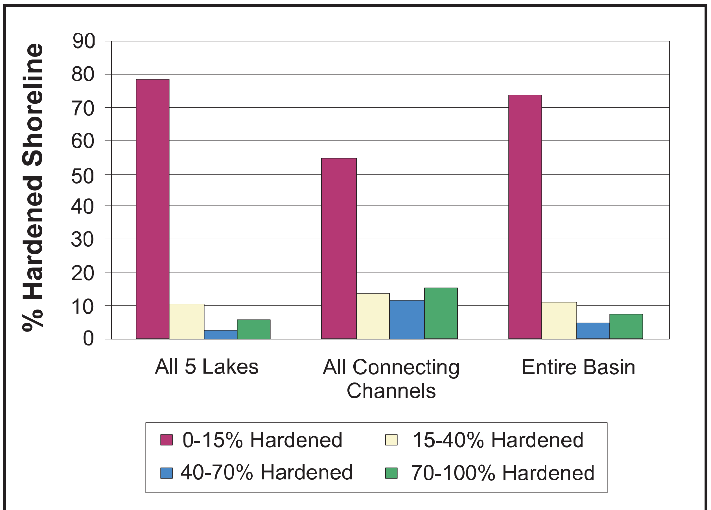

Figure 1. Shoreline hardening in the Great Lakes compiled from 1979 data for the state of Michigan and 1987-1989 data for the rest of the basin.
Source: Environment Canada and National Oceanic and Atmospheric Administration

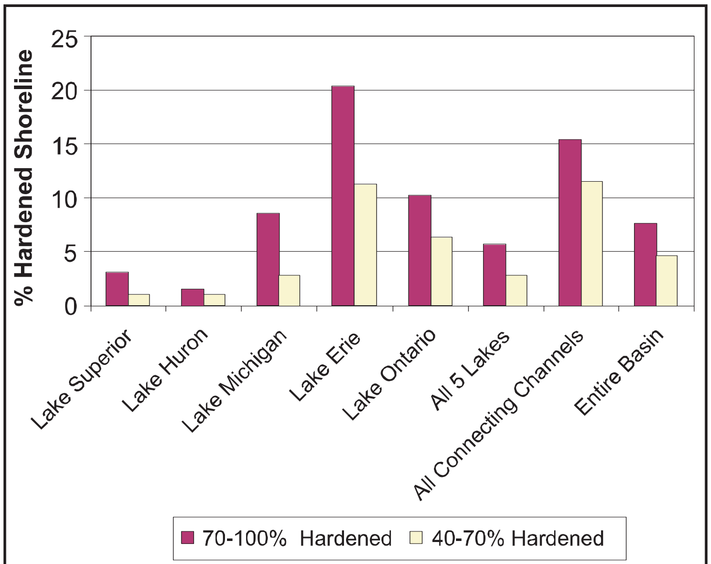

Figure 2. Shoreline hardened by lake compiled from 1979 data fro the state of Michigan and 1987-1989 for the rest of the basin.
Source: Environment Canada and National Oceanic and Atmospheric Administration

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

ment along its shorelines, and many property owners are hardening the shoreline to reduce the impacts of erosion.

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.

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.

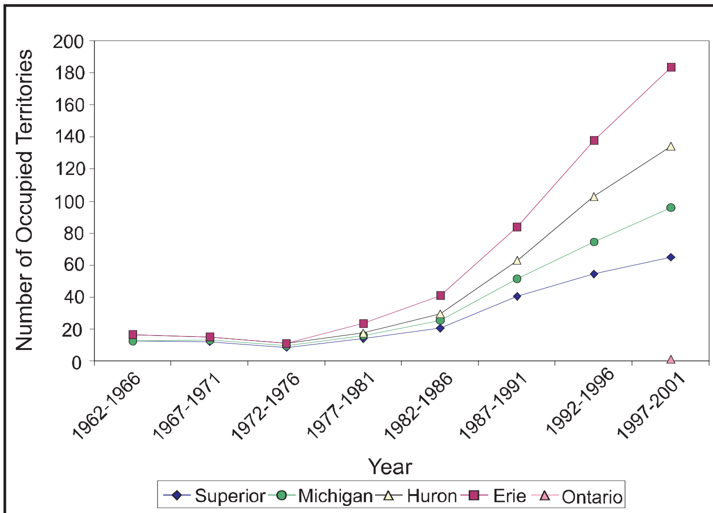

Figure 2. Average number of occupied bald eagle territories per year by lake.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources

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

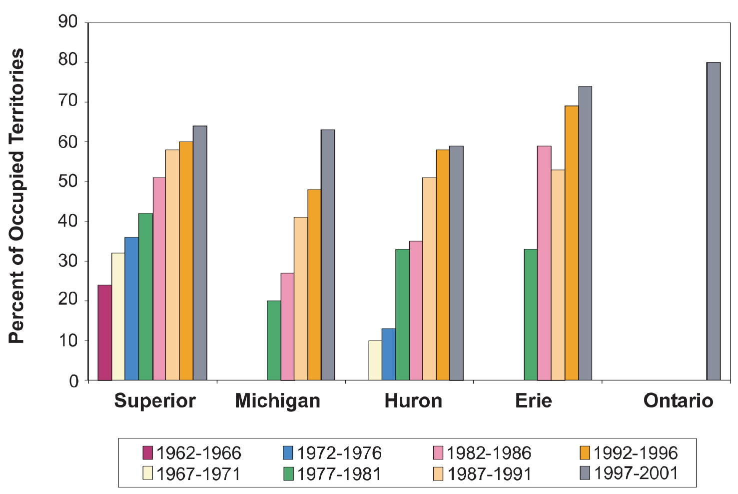

Figure 3. Average percentage of occupied territories fledging at least one young.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources

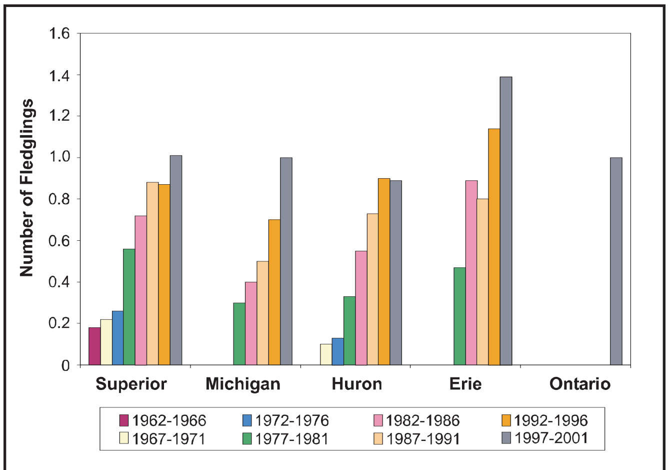

Figure 4. Average number of young fledged per occupied territory per year.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources

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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Additional data were contributed by: Ted Armstrong, Ontario Ministry of Natural Resources; Lowell Tesky, Wisconsin Department of Natural Resources; Cheryl Dykstra, Cleves, OH; Peter Nye, New York Department of Environmental Conservation; Michael Hoff, U.S. Fish and Wildlife Service. John Netto, U.S. Fish & Wildlife Service assisted with computer support.

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.

Population Monitoring and Contaminants Affecting the American Otter

Indicator #8147

This indicator report is from 2003.

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

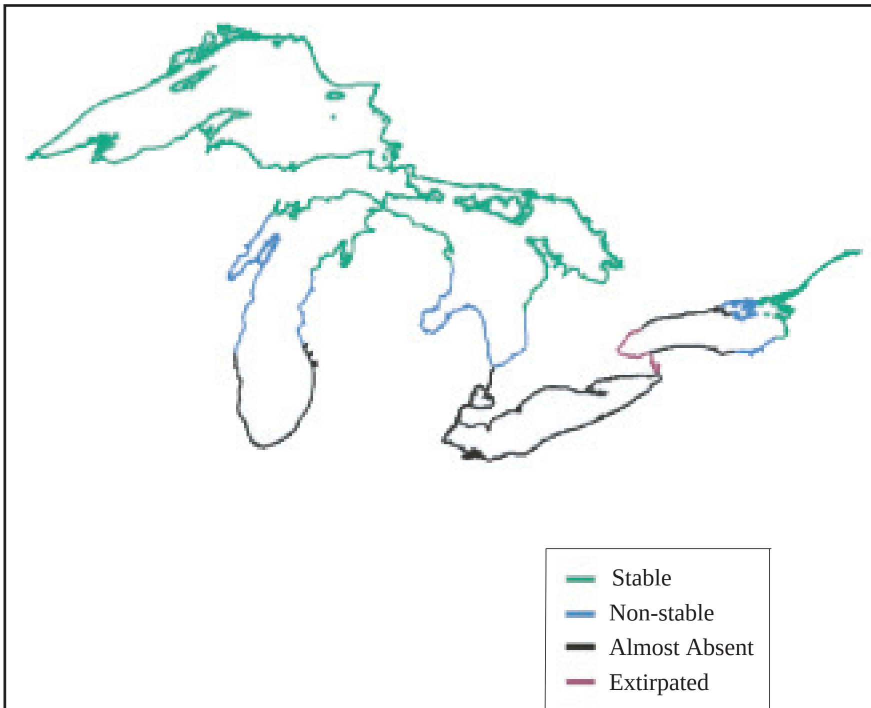

Figure 1. Great Lakes shoreline population stability estimates for the American otter.
Source: Thomas C.J. Doolittle, Bad River Band of Lake Superior Tribe of Chippewa Indians

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 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
Thomas C.J. Doolittle, Bad River Band of Lake Superior Tribe of Chippewa Indians, Odanah, WI.

Sources

Bishop, P., Gotie, R., Penrod, B., and Wedge, L. 1999. *Current status of river otter management in New York.* New York State Department of Environmental Conservation, Otter management team, Delmar, New York.

Bluett, R.D. 2000. Personal Communication. Illinois Department of Natural Resources, Springfield, IL.

Bluett, R.D., Anderson, E.A., Hubert, G.F., Kruse, G.W., and Lauzon, S.E. 1999. Reintroduction and status of the river otter (*Lutra canadensis*) in Illinois. *Transactions of the Illinois State Academy of Science* 92(1 and 2):69-78.

Brunström, B., Lund, B., Bergman, A., Asplund, L., Athanassiadis, I., Athanasiadou, M., Jensen, S., and Örberg, J. 2001. Reproductive toxicity in mink *(Mustela vison)* chronically exposed to environmentally relevant polychlorinated biphenyl concentrations. *Environ. Toxicol. Chem.* 20:2318-2327.

Chapman, J.A., and Pursley, D. (eds.). *Worldwide furbearers conference proceedings.* Worldwide Furbearer Conference, Inc. Frostburg, MD, pp.1752-1780.

Dawson, N. 2000. Personal Communication. Ontario Ministry of Natural Resources, Northwest Region. Thunder Bay, ON.

Dwyer, C.P. 2000a. Personal Communication. Ohio Division of Wildlife, Oak Harbor, OH.

Dwyer, C.P. 2000b. *Population assessment and distribution of river otters following their reintroduction into Ohio.* Crane Creek Wildlife Experiment Station, Ohio Division of Wildlife, Oak Harbor, OH.

Foley, F.E., Jackling, S.J., Sloan, R.J., and Brown, M.K. 1988. Organochlorine and mercury residues in wild mink and otter: comparison with fish. *Environ. Toxicol. Chem.* 7:363-374.

Friedrich, P.D. 2000. Personal Communication. Michigan Department of Natural Resources. East Lansing, MI.

Halbrook, R.S., Jenkins, J.H., Bush, P.B., and Seabolt, N.D. 1981. Selected environmental contaminants in river otters (*Lutra canadensis*) of Georgia and their relationship to the possible decline of otters in North America. In *Proc. Worldwide Furbearer Cong*., pp. 1752- 1762, Worldwide Furbearer Conference, Inc.

Hammill, J. 2000. Personal Communication. Michigan Department of Natural Resources. Crystal Falls, MI.

Henny, C.J., Blus, L.J., Gregory, S.V., and Stafford, C.J. 1981. PCBs and organochorine pesticides in wild mink and river otters from Oregon. In *Proc. Worldwide Furbearer Cong*., pp. 1763-1780.

Hochstein, J., Bursian, S., and Aulerich, R. 1998. Effects of dietary exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin in adult female mink *(Mustela vison). Arch. Environ. Contam. Toxicol.* 35:348-353.

Johnson, S. 2000. Personal Communication. Indiana Department of Natural Resources. Bloomington, IN.

Johnson, S.A., and Berkley, K.A. 1999. Restoring river otters in Indiana. *Wildlife Society Bull.* 27(2):419-427.

Johnson, S.A., and Madej, R.F. 1994. *Reintroduction of the river otter in Indiana – a feasibility study.* Indiana Department of Natural Resources, Bloomington, IN.

Kannan, K., Blankenship, A., Jones, P., and Giesy, J. 2000. Toxicity reference values for the toxic effects of polychlorinated biphenyls to aquatic mammals. *Human Ecological Risk Assessment* 6:181-201.

Kautz, M. 2000. Personal Communication. New York Department of Environmental Conservation, Delmar, NY.

Leonards, P., de Vries, T., Minnaard, W., Stuijfzand, S., de Voogt, P., Cofino, W., van Straalen, N., and van Hattum, B. 1995. Assessment of experimental data on PCB induced reproduction inhibition in mink, based on an isomer- and congener-specific approach using 2,3,7,8-tetrachlorodibenzo-p-dioxin toxic equivalency. *Environ. Toxicol. Chem.* 14:639-652.

Mason, C. 1989. Water pollution and otter distribution: a review. *Lutra* 32:97-131.

Mason, C., and Macdonald, S. 1993. Impact of organochlorine pesticide residues and PCBs on otters *(Lutra lutra)*: a study from western Britain. *Sci. Total Environ.* 138:127-145.

Mayack, D.T. 2000. Personal Communication. New York Department of Environmental Conservation, Gloversville, NY.

Michigan Department of Natural Resources. 2000a. *Distribution of otter harvest by section 1998-99.* East Lansing, MI.

Michigan Department of Natural Resources. 2000b. *River otter reproductive and harvest data 1995-1999.* East Lansing, MI.

New York State Department of Environmental Conservation. 1998-99. *Furbearer harvest by county and region.* Albany, NY.

Ohio Division of Wildlife. 1999-2000. *Watersheds with river otter observations.* Oak harbor, OH.

Olson, J. 2000. Personal Communication. Furbearer Specialist, Wisconsin Department of Natural Resources, Park Falls, WI.

Ontario Ministry of Natural Resources. 2000. *Ontario furbearer population ranks through trapper questionnaires by Wildlife Assessment Unit*. Thunder Bay, ON.

Roos, A., Greyerz, E., Olsson, M., and Sandegren, F. 2001. The otter *(Lutra lutra)* in Sweden? Population trends in relation to 3DDT and total PCB concentrations during 1968-99. *Environ. Pollut.* 111:457-469.

Route, W.T., and Peterson, R.O.1988. *Distribution and abundance of river otter in Voyageurs National Park, Minnesota*. Resource Management Report MWR-10. National Park Service, Omaha, NE.

Sheffy, T.B., and St. Amant, J.R. 1982. Mercury burdens in furbearers in Wisconsin. *J. Wildlife Manage*. 46:1117-1120.

Wisconsin Department of Natural Resources. 2000a. *Distribution of otter harvest by management unit 1998-99*. Madison, WI.

Wisconsin Department of Natural Resources. 2000b. *Otter population model statewide 1982-2005.* Madison, WI.

Wisconsin Department of Natural Resources. 1979-1998. *Summary of otter reproductive information*. Madison, WI.

Wren, C. 1991. Cause-effect linkages between chemicals and populations of mink (*Mustela vison*) and otter (*Lutra canadensis*) in the Great Lakes basin. *J. Toxicol Environ. Health* 33:549-585.

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.

Forest Lands - Conservation of Biological Diversity
Indicator #8500

Note: This indicator includes three components or measures.

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 as defined by IUCN or other classification systems

Assessment: Mixed, Improving

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 processes that are essential to supplying high quality water and protecting the physical integrity of the watershed.

Ecosystem Objective
Component (1) summarizes total forest area and area by forest type. The extent and diversity of forest cover are positive indicators of basin health. Water draining forested watersheds is of high quality, as measured by sediment yields, nutrient loadings, contaminant concentrations and temperatures. Forests also control soil erosion, increase groundwater infiltration, stabilize shorelines and regulate storm run-off. Leaf litter and woody debris provide critical food and habitat for fish and other aquatic wildlife.

Component (2) summarizes the structure of forest based on age class. Many ecological processes and wildlife species are associated with vegetative structures (age, diameter and height of vegetation) and successional stages (variable species of vegetation).

Component (3) summarizes the extent of forest by type in a protected area category. Protected status ensures that specified tracts of land remain under forest cover, and is indicative of the value a society and its policymakers place on forest conservation.

State of the Ecosystem
Component (1): Forests cover 27.8 million hectares, or about half (51%), of the land in the Great Lakes basin. The U.S. portion of the basin contains 14.8 million hectares of forests (47% of the U.S. basin), while the Canadian portion contains 13.0 million hectares (57% of the Canadian basin).

Maple-beech-birch is the most extensive forest type, representing 7.6 million hectares, or 27% of total forest area in the basin. Aspen-birch forests constitute the second-largest forest type, covering 6.5 million hectares, or 23% of the total. Other major types include spruce-fir forests (5.0 million hectares, or 18% of total forest area) and white-red-jack pine forests (2.7 million hectares, or 10% of total forest area). Complete data are available in Table 1.

Forest Type	Area of Forest Type (ha)	Total Forest Area (%)
Maple-Beech-Birch	7,574,099	27.30%
Aspen-Birch	6,460,568	23.30%
Spruce-Fir	4,964,154	17.90%
White-Red-Jack Pine	2,699,360	9.70%
Oak-Hickory	1,838,136	6.60%
Elm-Ash-Cottonwood	1,632,339	5.90%
Spruce-Jack Pine-Aspen	480,402	1.70%
Other Softwoods	182,219	0.70%
Oak-Pine	178,744	0.60%
Other	519,266	1.90%
Non-stocked	1,262,441	4.50%
Total Forest Area	**27,791,728**	
Total Land Area in Basin	**54,757,612**	

Table 1. Forest area by forest type. (Non-stocked = timber land less than 10% stocked with live trees)
Source: Ontario Ministry of Natural Resources and U.S. Department of Agriculture

Implications for the health of Great Lakes forests and the basin ecosystem are difficult to establish. On a positive note, total forest area appears to have increased across the Great Lakes basin in recent decades (see Table 2). Expanding forest area is associated with positive impacts on water quality and quantity. Due to changes in data definitions, however, it is difficult to determine whether the growth in forest area is occurring in riparian zones, where the impact on water quality is the greatest.

Moreover, 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. 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 "Historical Range of Variation in the Great Lakes Forests of Minnesota, Wisconsin and Michigan" at the end of this report).

Component (2): Basin-wide, the 41-60 and 61-80 year age-classes are dominant and together represent almost 53% of total forest area. Forests under 40 years of age make up a further 23%, while those in the 100+ year age-classes constitute 9% of total forest area. Table 3 contains complete data on age-class distribution by area within each forest type.

State/Province	Forest Area Estimates (ha) Earliest Available Area (ha)	Forest Area Estimates (ha) Most Recently Available Area (ha)	Change (ha)	% Change
Illinois	nil (1985)	5,726 (2002)	***	***
Indiana	118,414 (1986)	121,852 (2002)	3,438	2.90%
Michigan	7,433,913 (1980)	7,848,153 (2001)	414,240	5.60%
Minnesota	1,128,086 (1977)	1,208,050 (2002)	79,964	7.10%
New York	2,616,380 (1993)	2,909,938 (2002)	293,558	11.20%
Ohio *	N/A	453,741 (1991)	N/A	N/A
Pennsylvania	64,331 (1989)	76,885 (2002)	***	***
Wisconsin	2,053,865 (1983)	2,122,031 (2002)	68,166	3.30%
Ontario **	N/A	13,045,401 **	N/A	N/A

* Ohio data only available for 1991
** Ontario data a mosaic of 1978-2001 data
*** Illinois and Pennsylvania excluded from calculations due to small sample area

Table 2. Expansion in forest area, by state/province
Source: Ontario Ministry of Natural Resources and U.S. Department of Agriculture

Because forests are dynamic and different tree species have different growth patterns, age distribution varies by forest type. Aspen-birch and white-red-jack pine forests tend to be younger, being more concentrated in the 21-40 and 41-60 year age classes, while maple-beech-birch forests are heavily concentrated in the 61-80 year age class. Spruce-fir forests contain significant old growth, with 21% by area in the 100+ year age classes, more than twice the overall level (9%) within those age classes.

The age-class distribution of U.S. basin forests mirrors the overall trend, but with a higher concentration in the 41-60 and 61-80 year age classes, which contain 58% of total forest area in the U.S. portion of the basin. Canadian Great Lakes forests have a distribution balanced towards older age classes, with 17% by area in the 100+ year age classes, compared to 3% in the U.S. basin. Also, a wider range of forest types is represented in Canadian old growth forests. At the same time, Canadian basin forests contain a substantially higher area of non-stocked forests (timber land less than 10% stocked with live trees) that by definition lies almost exclusively in the 0-20 year age class. Canadian basin forests also have a relatively small area in the 21-40 year age class.

What this age-class data means for forest and basin health is not clear. 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.

Data on the extent of forest area by successional stage are not available. Although certain tree species are 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.

Component (3): In the U.S. basin, 3.5% of forested land, comprising 517,000 hectares, is in a protected area category. Among major forest types, 5.4% of maple-beech-birch (308,000 hectares), 2.7% of aspen-birch (73,000 hectares), 4.4% of spruce-fir (79,000 hectares) and 0.6% of white-red-jack pine forests (7,000 hectares) are considered to have protected status. The "other softwoods" category has the highest protection rate, with 7.7%, or 12,000 of its 157,000 hectares, protected from harvest.

In the Canadian portion of the basin, 10.8% of forest area, or 1.4 million hectares, are protected. Protection rates range from 9.2% for maple-beech-birch (172,000 hectares) and 10.7% for spruce-fir forests (340,000 hectares), to 12.7% for white-red-jack pine (191,000 hectares) and 13.0% for aspen-birch forests (490,000 hectares). The oak-pine category has the highest protection rate, with 22.5%, or 20,000 of its 90,000 hectares, under protected status. See complete data in Table 4.

Implications of extent of forest area with protected status for forest and basin health are again difficult to establish. On one hand, the extent of forest area with protected status appears to have increased in recent decades (see Table 5). Particularly large increases in protected forest area in Ontario, New York and Minnesota have more than offset reported declines in Michigan and Wisconsin. However, due to changes in data definitions, it is difficult to determine whether the expansion or contraction of protected forests is occurring in riparian zones, where the impact on water quality is the greatest.

There is also no consensus on what proportion of forest land should be protected. Nationally, forest protection rates are estimated to be 8.4% in Canada (WWF 1999) and 14% in the U.S. (Guldin and Kaiser 2004). 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 had a different jurisdiction than the Great Lakes basin in mind when deciding where to locate protected areas. Since forests are dynamic, 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

Combined

Forest Type	Age Class (in years)									
	0-20	**21-40**	**41-60**	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-200**	**200+**
Maple-Beech-Birch	4.90%	10.20%	25.90%	33.30%	14.60%	4.40%	2.50%	1.70%	0.80%	0.10%
Aspen-Birch	10.50%	14.90%	28.80%	27.80%	13.50%	3.50%	0.80%	0.10%	< 0.1%	0.10%
Spruce-Fir	4.10%	7.20%	21.50%	26.90%	19.40%	9.80%	7.20%	3.30%	0.50%	0.10%
White-Red-Jack Pine	9.90%	16.30%	26.40%	22.60%	15.10%	5.70%	2.40%	0.90%	0.50%	0.20%
Oak-Hickory	7.80%	15.90%	26.60%	27.00%	11.80%	3.30%	0.60%	0.10%	< 0.1%	< 0.1%
Elm-Ash-Cottonwood	6.80%	21.10%	39.00%	20.40%	6.10%	2.10%	0.70%	0.30%	< 0.1%	-
Spruce-Jack Pine-Aspen	4.50%	8.50%	19.90%	28.40%	22.40%	8.80%	4.40%	1.90%	1.10%	0.10%
Other Softwoods	6.50%	42.00%	38.40%	4.60%	3.70%	2.10%	1.40%	0.80%	0.20%	-
Oak-Pine	4.40%	12.50%	21.30%	34.90%	18.50%	5.50%	2.00%	0.60%	0.20%	< 0.1%
Other	2.10%	7.30%	30.20%	38.80%	15.50%	3.90%	1.50%	0.40%	0.10%	0.10%
Non-stocked	99.50%	0.20%	0.10%	0.10%	0.10%	< 0.1%	-	-	-	< 0.1%
TOTAL	**11.10%**	**12.10%**	**25.50%**	**27.00%**	**14.00%**	**4.90%**	**2.60%**	**1.20%**	**0.40%**	**< 0.1%**

U.S. Great Lakes Basin

Forest Type	Age Class (in years)									
	0-20	**21-40**	**41-60**	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-200**	**200+**
Maple-Beech-Birch	6.30%	12.50%	30.50%	35.50%	10.90%	1.60%	0.30%	0.20%	< 0.1%	-
Aspen-Birch	21.40%	24.80%	30.90%	19.10%	3.30%	0.40%	0.10%	< 0.1%	-	0.10%
Spruce-Fir	5.90%	12.20%	30.40%	28.50%	15.50%	4.20%	1.60%	1.30%	0.30%	0.20%
White-Red-Jack Pine	12.50%	26.80%	36.10%	16.80%	5.80%	1.60%	0.40%	-	-	0.10%
Oak-Hickory	8.30%	16.60%	27.20%	26.40%	10.40%	3.20%	0.50%	0.10%	-	-
Elm-Ash-Cottonwood	7.80%	21.40%	38.60%	18.70%	6.00%	2.20%	0.80%	0.30%	-	-
Spruce-Jack Pine-Aspen										
Other Softwoods	7.20%	47.90%	42.90%	1.50%	-	-	-	-	-	-
Oak-Pine	7.90%	22.20%	27.00%	35.40%	7.40%	-	-	-	-	-
Other										
Non-stocked	100.00%	-	-	-	-	-	-	-	-	-
TOTAL	**10.50%**	**17.50%**	**31.30%**	**26.90%**	**8.90%**	**1.90%**	**0.50%**	**0.30%**	**< 0.1%**	**< 0.1%**

Canadian Great Lakes Basin

Forest Type	Age Class (in years)									
	0-20	**21-40**	**41-60**	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-200**	**200+**
Maple-Beech-Birch	0.70%	3.40%	11.80%	26.60%	25.70%	13.10%	8.80%	6.20%	3.20%	0.50%
Aspen-Birch	2.80%	7.90%	27.20%	33.90%	20.70%	5.80%	1.30%	0.20%	0.10%	< 0.1%
Spruce-Fir	3.10%	4.30%	16.60%	26.00%	21.60%	13.00%	10.40%	4.50%	0.70%	0.10%
White-Red-Jack Pine	7.90%	8.00%	18.60%	27.30%	22.50%	9.00%	4.10%	1.50%	0.90%	0.20%
Oak-Hickory	1.30%	5.10%	18.90%	36.20%	31.90%	4.90%	1.10%	0.30%	0.30%	0.10%
Elm-Ash-Cottonwood	2.30%	19.90%	40.60%	28.00%	7.00%	1.70%	0.50%	0.10%	0.10%	< 0.1%
Spruce-Jack Pine-Aspen	4.50%	8.50%	19.90%	28.40%	22.40%	8.80%	4.40%	2/0%	1.10%	0.10%
Other Softwoods	2.20%	5.00%	10.50%	23.80%	26.30%	14.70%	10.40%	6.00%	1.10%	-
Oak-Pine	0.90%	2.00%	15.60%	34.30%	29.50%	11.00%	4.10%	1.30%	0.40%	< 0.1%
Other	2.10%	7.30%	30.20%	38.80%	15.50%	3.90%	1.50%	0.40%	0.10%	0.10%
Non-stocked	99.50%	0.30%	0.10%	0.10%	0.10%	< 0.1%	-	-	-	< 0.1%
TOTAL	**11.80%**	**5.90%**	**19.00%**	**27.00%**	**19.70%**	**8.40%**	**4.90%**	**2.30%**	**0.80%**	**0.10%**

Table 3. Age-class distribution as a percentage of area within forest type
(Non-stocked = timber land less than 10% stocked with live trees)
Source: Ontario Ministry of Natural Resources and U.S. Department of Agriculture

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 regula-

U.S. Great Lakes Basin			
Forest Type	Area (ha)	Protected Area (ha)	% Protected
Maple-Beech-Birch	5,693,178	308,332	5.40%
Aspen-Birch	2,684,602	73,402	2.70%
Spruce-Fir	1,784,559	79,060	4.40%
White-Red-Jack Pine	1,195,641	6,639	0.60%
Oak-Hickory	1,716,488	21,823	1.30%
Elm-Ash-Cottonwood	1,331,321	15,863	1.20%
Spruce-Jack Pine-Aspen	-	-	-
Other Softwoods	156,901	12,139	7.70%
Oak-Pine	89,200	-	-
Other	-	-	-
Non-stocked	94,485	-	-
TOTAL	**14,746,328**	**517,260**	**3.50%**

Canadian Great Lakes Basin			
Forest Type	Area (ha)	Protected Area (ha)	% Protected
Maple-Beech-Birch	1,880,921	172,045	9.20%
Aspen-Birch	3,775,966	490,108	13.00%
Spruce-Fir	3,179,595	339,953	10.70%
White-Red-Jack Pine	1,503,720	191,345	12.70%
Oak-Hickory	121,648	18,819	15.50%
Elm-Ash-Cottonwood	301,019	8,096	2.70%
Spruce-Jack Pine-Aspen	480,402	53,180	11.10%
Other Softwoods	25,318	2,099	8.30%
Oak-Pine	89,544	20,138	22.50%
Other	519,266	55,991	10.80%
Non-stocked	1,168,003	50,754	4.40%
TOTAL	**13,045,401**	**1,402,527**	**10.80%**

Table 4. Protected area by forest type
(Non-stocked = timber land less than 10% stocked with live trees)
Source: Ontario Ministry of Natural Resources and U.S. Department of Agriculture

State/Province	Protected Forest Area (ha)		Change (ha)
	Earliest Available Area	Most Recently Available Area	
Illinois	nil (1985)	1,538 (2002)	**
Indiana	5,828 (1986)	10,938 (2002)	5,110
Michigan	275,936 (1980)	124,034 (2001)	-151,902
Minnesota	567 (1977)	57,620 (2002)	57,053
New York	53,765 (1993)	278,157 (2002)	224,392
Ohio *	N/A	21,215 (1991)	N/A
Pennsylvania	1,013 (1989)	nil (2002)	**
Wisconsin	51,194 (1983)	23,758 (2002)	-27,436
Ontario	585,072 (1998)	1,402,528 (2001)	817,456

* Ohio data only available for 1991
** Illinois and Pennsylvania excluded from calculations due to small sample area

Table 5. Changes in protected forest area by state/province
Source: Ontario Ministry of Natural Resources and U.S. Department of Agriculture

tion," 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 U.S., Ontario and IUCN definitions, but 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.

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.

Management Implications

At this time, forest lands within the basin are enrolled in sustainable forestry certification programs such as the Sustainable Forestry Initiative (SFI), the Forest Stewardship Council, and the Canadian Standards Association. For example, there are currently more than 14 million acres in the U.S. and more than eight million acres in Canada enrolled in the SFI program alone. SFI is a comprehensive system of principles, objectives and performance measures developed by foresters, conservationists and scientists that combines the perpetual growing and harvesting of some trees with the protection of wildlife, plants, soil and water quality. The program requires participants to manage the quality and distribution of wildlife habitats and contribute to the conservation of biological diversity by developing and implementing stand-and landscape-level measures that promote habitat diversity and the conservation of forest plants and animals including aquatic fauna.

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Sources
Alerich, C.L., Klevgard, L., Liff, C., and Miles, P.D. 2004. *The Forest Inventory and Analysis Database: Database Description and Users Guide Version 1.7*. U.S. Department of Agriculture (USDA) Forest Service, North Central Research Station. NC-218. http://ncrs2.fs.fed.us/4801/fiadb/fiadb_documentation/FIADB_DOCUMENTATION.htm.

Canadian Council of Forest Ministers. 2000. *Criteria and Indicators of Sustainable Forest Management in Canada: National Status 2000*. http://www.ccfm.org/ci/2000_e.html.

Canadian Great Lakes basin forest data are courtesy of Larry Watkins (Ontario Ministry of Natural Resources).

Carpenter, C., Giffen, C., and Miller-Weeks, M. 2003. *Sustainability Assessment Highlights for the Northern United States.* U.S. Department of Agriculture (USDA) Forest Service, Northeastern Area State and Private Forestry. NA-TP-05-03. http://www.na.fs.fed.us/sustainability/pdf/front_cover.pdf.

Cole, K., Stearns, F., Guntenspergen, G., Davis, M., and Walker, K. 1998. Historical Landcover Changes in the Great Lakes Region. In *Perspectives on the land-use history of North America: a context for understanding our changing environment*, ed. T.D Sisk, Ch. 6. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003. http://biology.usgs.gov/luhna/chap6.html.

Eubanks, C.E., and Meadows, D. 2002. A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization. In *U.S. Department of Agriculture (USDA). Forest Service, Technology and Development Program.* FS-683. http://www.fs.fed.us/publications/soil-bio-guide/.

Guldin, R.W., and Kaiser, H.F. 2004. *National Report on Sustainable Forests – 2003*. U.S. Department of Agriculture (USDA) Forest Service. FS-766. 88pp. http://www.fs.fed.us/research/sustain/documents/SustainableForests.pdf.

Historical statewide forest data for Minnesota, Wisconsin and Michigan are courtesy of Kenneth Cole (USGS) and were clipped to Great Lakes basin boundary using GIS software by the author.

Ontario Ministry of Natural Resources (OMNR). 2002. State *of the Forest Report, 2001*. Queen's Printer for Ontario. http://ontariosforests.mnr.gov.on.ca/spectrasites/Viewers/showArticle.cfm?id=20661E52-EE91-453D9BD475CE675F7D1A&method=DISPLAYFULLNOBARNOTITLE_R&ObjectID=20661E52-EE91-453D-9BD475CE675F7D1A.

Sedell, J., Sharpe, M., Dravnieks Apple, D., Copenhagen, M., and Furniss, M. 2000. *Water and the Forest Service.* U.S. Department of Agriculture (USDA) Forest Service, Policy Analysis. FS-660. http://www.fs.fed.us/.ftproot/pub/water/water.pdf.

Smith, W.B. 2004. *United States 2003 Report on Sustainable Forests, Data Report: Criterion 1, Indicators 1, 2, 3, 4, Conservation of Biological Diversity*. U.S. Department of Agriculture (USDA) Forest Service. FS-766A. 24pp. http://www.fs.fed.us/research/sustain/contents.htm.

U.S. Department of Agriculture (USDA) Forest Service. *2000 RPA Assessment of Forest and Range Lands*. FS-687. http://svinet2.fs.fed.us/pl/rpa/publications_in_support_of_the_2.htm.

U.S. Great Lakes basin forest data were compiled and analyzed on GIS software by the author using the U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis database, with assistance from Geoffrey Holden (USDA Forest Service). Raw data files available for download at: http://ncrs2.fs.fed.us/4801/fiadb/fiadb17_dump/fiadb17_dump.htm.

World Wildlife Fund (WWF). 1999. *Canada's commitment to forest protected areas: Forests for life*. WWF Status Report. World Wildlife Fund Canada. Toronto, ON. 17 p. Cited in Canadian Council of Forest Ministers. 2000. Criteria and Indicators of Sustainable Forest Management in Canada: National Status 2000. 7pp.

Authors' Commentary
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 certainly add to longstanding debates on strategies for sustainable forest management.

8500 Forest Lands – Conservation of Biological Diversity Supplemental Section

Historical Range of Variation in the Great Lakes Forests of Minnesota, Wisconsin and Michigan

Data on the historic range of variation in extent of total forest area and area by forest type since the time of European settlement are available for Minnesota, Wisconsin and Michigan in a U.S. Geological Survey (USGS) study (Cole *et al.* 1998). Pre-settlement data were adapted from the General Land Office (GLO) surveys conducted between 1815 and 1866, while modern data were compiled from the USDA Forest Service's Forest Inventory and Analysis (FIA) database for the period 1977-1983.

Vegetation units in the GLO survey were simplified to allow comparison to the FIA forest type groups. The re-classification was conducted based on dominant tree species, as follows:

The data presented in the USGS study are statewide for Minnesota, Wisconsin and Michigan, so the USEPA - GLNPO clipped the data using GIS software to extract information relevant to the portions of each state that lie within the Great Lakes watershed. This exercise revealed that extent of area covered by forest declined by 37% between the mid-19th century and 1977-1983, due primarily to the conversion of northern mesic forest (maple-beech-birch) and oak forest (oak-hickory) in southern Wisconsin and Michigan to urban and agricultural use.

By forest type, area covered by pine forests (white-red-jack pine) declined by 81%, northern mesic forests (maple-beech-birch) by 64%, and boreal forests (spruce-fir) by 63% over the same period, although the area covered by aspen-birch forests increased by 212%. The late-19th century was marked by extensive logging of pine forests and subsequent conversion to early successional aspen-birch forests. Figures 1 and 2 depict the changes in forest cover.

However, comparing FIA data from 1977-1983 to the most recent data collected in 2001-2002 for these three states indicates that further changes have occurred over the past quarter-century. Total forest area has expanded by 5% over the period, while area covered by white-red-jack pine forests has increased by 18%, and maple-beech-birch forests (northern mesic) by 13%. At the same time, aspen-birch forests have retreated by 3%, and spruce-fir (boreal) forests have declined by 12%. Meanwhile, the area of non-stocked forest land (timber land less than 10% stocked with live trees) has dropped by 9%. These data suggest a maturation and steady recovery over recent decades in the Great Lakes forests of Minnesota, Wisconsin and Michigan, as reflected by the progression of natural successional patterns, replanting of non-forest areas, and regeneration of non-stocked forest lands.

GLO Vegetation Unit Group	Major Tree Species	FIA Forest Type
Boreal Forest-Conifer Swamp	White spruce, balsam fir, northern white cedar, swamp conifer forest of black spruce and tamarack	Spruce-fir
Pine Forest-Barrens	White pine, red pine, jack pine	White-red-jack pine
Northern Mesic Forest	Sugar maple, basswood, yellow birch, beech, hemlock, some oaks	Maple-beech-birch
Aspen-Birch	Aspen, paper birch	Aspen-birch
Oak Forest-Savanna	Forest and savanna areas of red oak, black oak, white oak and bur oak	Oak-hickory
Wet Mesic Forest	Lowland forests of American elm, green and black ash, silver maple	Elm-ash-cottonwood

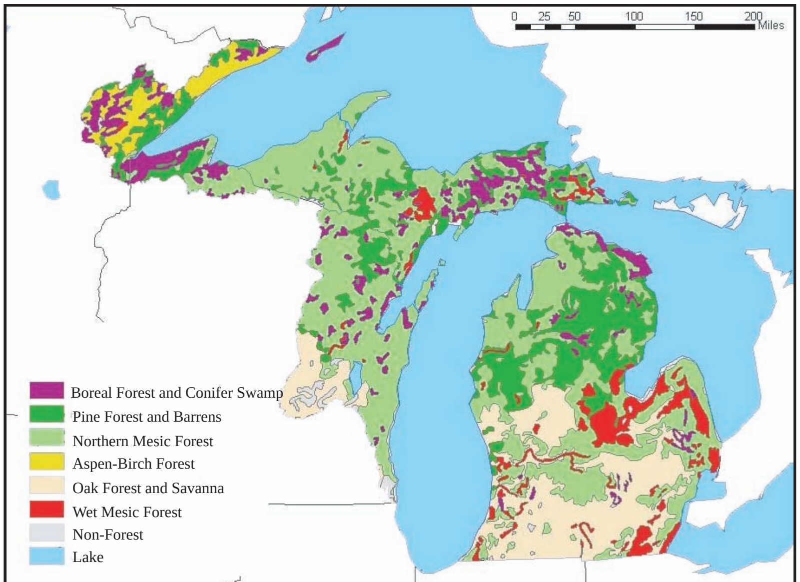

Figure 1. Pre-settlement Forest
Source: U.S. Geological Survey, based on General Land Office survey (1815-1866)

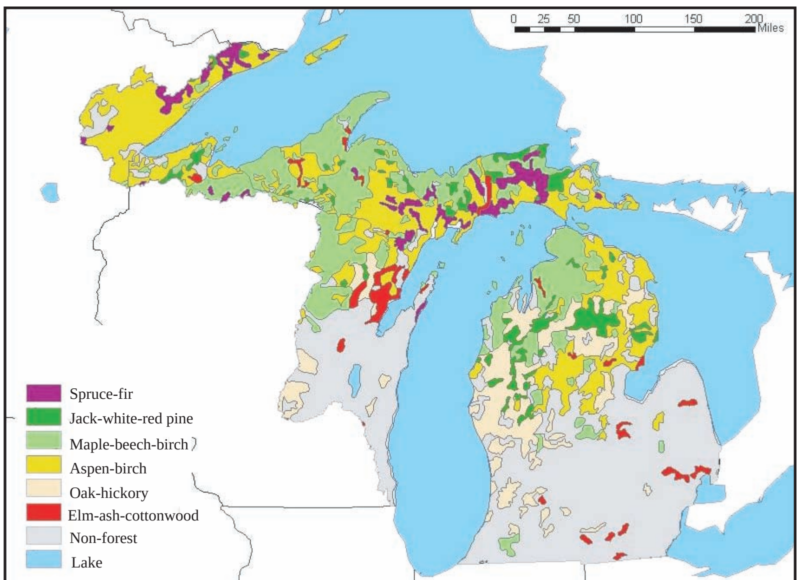

Figure 2. Modern Forest
Source: U.S. Geological Survey, based on U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Database (1977-1983)

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.

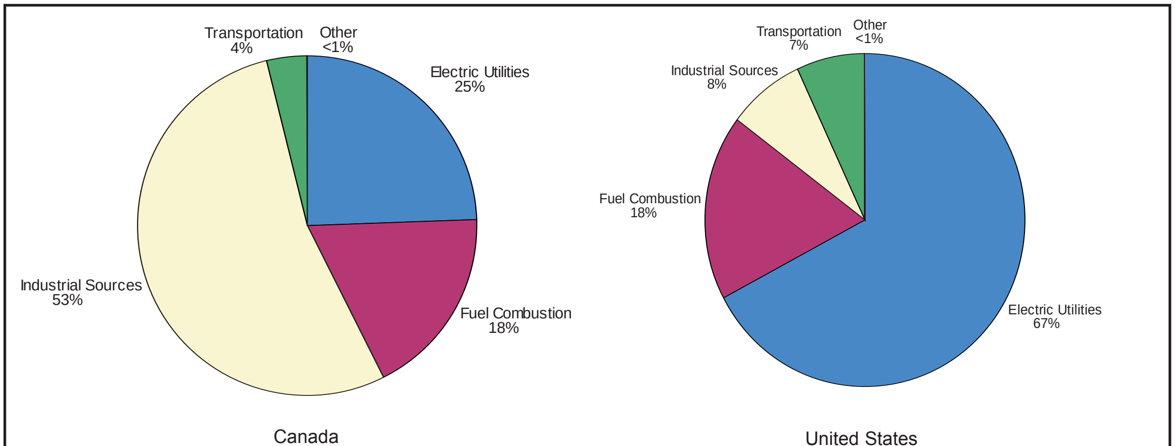

Figure 1. Sources of Sulfur Dioxide Emissions in Canada and the U.S. (1999)
Source: Figure 4 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf and Environment Canada 1999 National Pollutant Release Inventory Data and U.S. Environmental Protection Agency 1999 National Emissions Inventory Documentation and Data

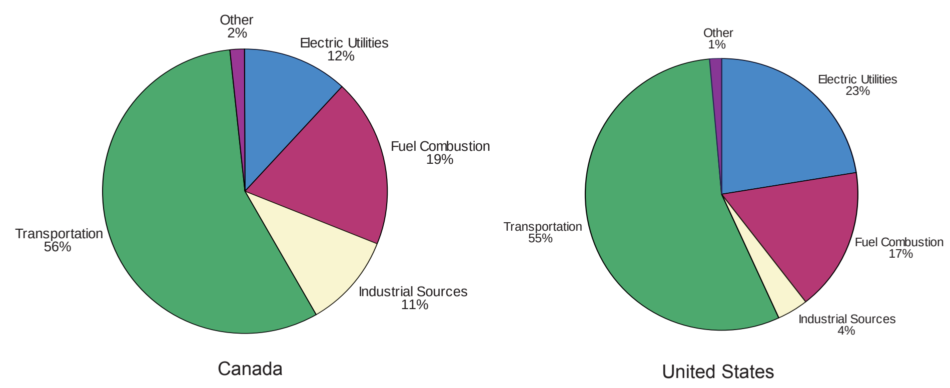

Figure 2. Sources of Nitrogen Oxides Emissions in Canada and the U.S. (1999)
Source: Figure 6 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf and Environment Canada 1999 Pollutant Release Inventory Data and U.S. Environmental Protection 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.

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-

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.

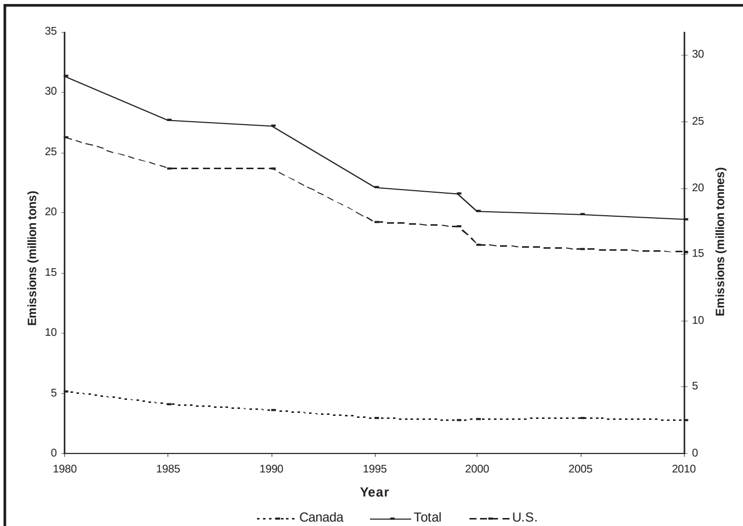

Figure 3. Canada-U.S. sulfur dioxide emissions, 1980-2010
Source: Figure 3 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf and U.S. Environmental Protection Agency. Projection year emissions data. http://www.epa.gov/otaq/models/hd2007/r00020.pdf

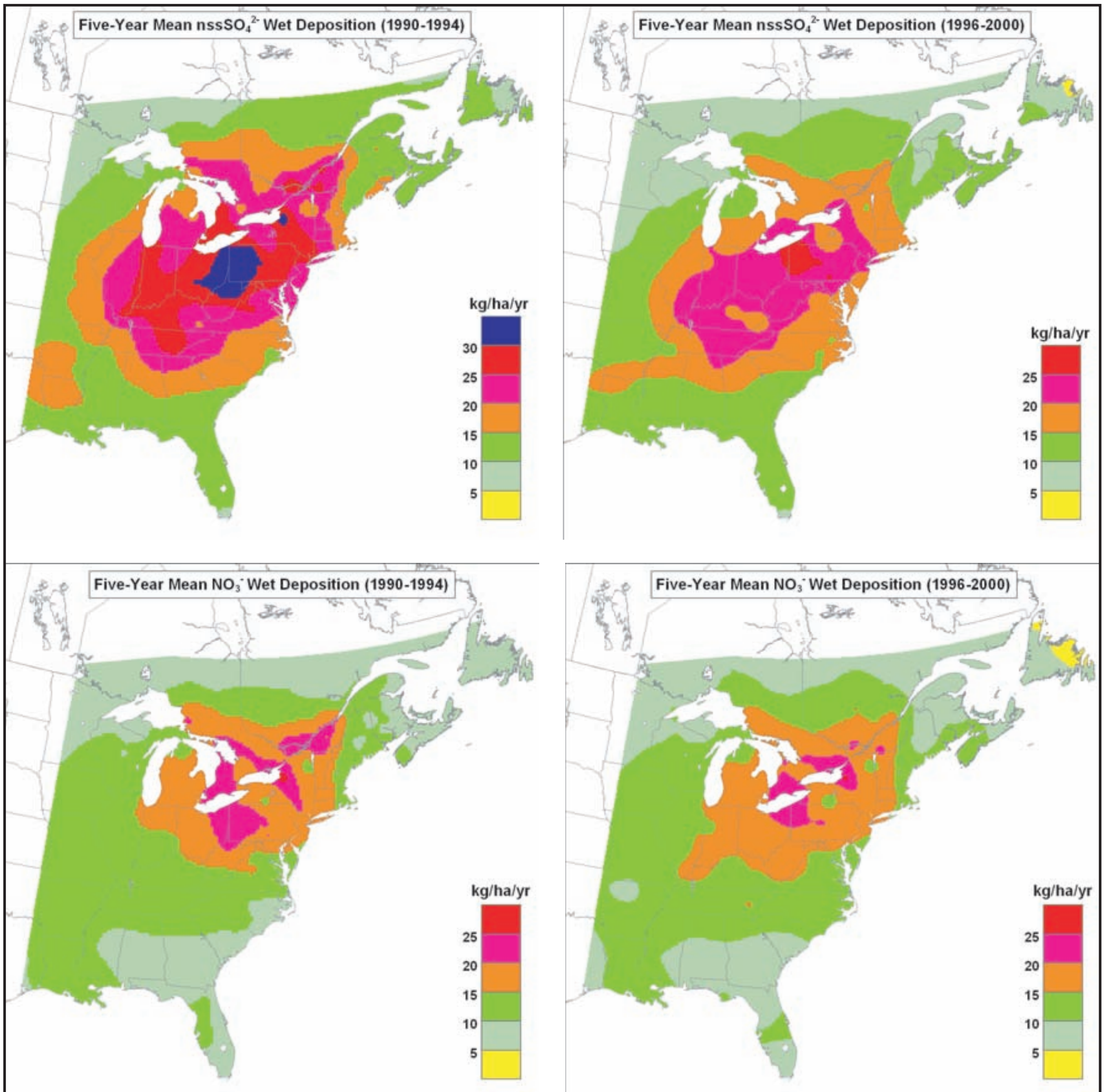

Figure 4. Five-year mean patterns of wet non-sea-salt-sulfate ($nssS0_4^{2-}$) and wet nitrate deposition for the periods 1990-1994 and 1996-2000.
Source: Figures 9 through 12 of Canada - United States Air Quality Agreement: 2002 Progress Report. http://www.epa.gov/airmarkets/usca/airus02.pdf, and Jeffries, 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.

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Authors: Dean S. Jeffries, National Water Research Institute, Environment Canada, Burlington, ON;
Robert Vet, Meteorological Service of Canada, Environment Canada, Downsview, ON;
Silvina Carou, Meteorological Service of Canada, Environment Canada, Downsview, ON;
Kerri Timoffee, Manager, Acid Rain Program, Environment Canada, Gatineau, QC; and
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Sources

Canada – United States Air Quality Committee. 2002. *United States - Canada Air Quality Agreement: 2002 Progress Report*. http://www.epa.gov/airmarkets/ usca/airus02.pdf, last accessed June 17, 2004.

Canadian Council of Ministers of the Environment (CCME). 2004. *2002 Annual progress Report on the Canada-Wide Acid Rain Strategy for Post-2000*. ISBN 0-622-67819-2. http://dev.sites1.miupdate.com/1/assets/pdf/2002_ar_annual_rpt_e.pdf, last accessed June 21, 2004.

Canadian Council of Ministers of the Environment (CCME). 2002. 2001 Annual Progress Report on the Canada-Wide Acid Rain Strategy for Post-2000. ISBN 0-662-66963-0. http://www.ccme.ca/assets/pdf/acid_rain_e.pdf, last accessed July 16, 2004.

Driscoll, C.T., Lawrence, G.B., Bulger, A.J., Butler, T.J., Cronan, C.S., Eagar, C., Lambert, K.F., Likens, G.E., Stoddard, J.L., and Weathers, K.C. 2001. *Acid Rain Revisited: advances in scientific understanding since the passage of the 1970 and 1990 Clean Air Act Amendments*. Hubbard Brook Research Foundation. Science LinksTM Publication Vol.1, no.1.

Environment Canada. 2005. *2004 Canadian Acid Deposition Science Assessment: Summary of Key Results*. http://www.msc-smc.ec.gc.ca/saib/acid/acid_e.html.

Environment Canada. 2004. *2002 National Pollutant Release Inventory Data*.

http://www.ec.gc.ca/pdb/npri/npri_dat_rep_e.cfm#highlights, last accessed June 29, 2004.

Environment Canada. 2003a. *2001 National Pollutant Release Inventory: National Overview*. http://www.ec.gc.ca/pdb/npri/npri_dat_rep_e.cfm#annual2001, last accessed June 29, 2004.

Environment Canada. 2003b. *Cleaner Air through Cooperation: Canada – United States Progress under the Air Quality Agreement 2003*. ISBN 0-662-34082-5. http://www.epa.gov/airmarkets/usca/brochure/brochure.htm, last accessed June 17, 2004.

Environment Canada. 2003c. *Environmental Signals: Canada's National Environmental Indicator Series 2003.* http://www.ec.gc.ca/soer-ree/English/Indicator_series/default.cfm#pic, last accessed June 29, 2004.

Environment Canada. *National Atmospheric Chemistry Database and Analysis Facility*. Meteorological Service of Canada, Downsview, ON.

Jeffries, D.S., Clair, T.A., Couture, S., Dillon, P.J., Dupont, J., Keller, W., McNicol, D.K., Turner, M.A., Vet, R., and Weeber, R. 2003. Assessing the recovery of lakes in southeastern Canada from the effects of acidic deposition. *Ambio*. 32(3):176-182.

National Atmospheric Deposition Program. *A Cooperative Research Support Program of the State Agricultural Experiment Stations (NRSP-3) Federal and State Agencies and Non-Governmental Research Organizations*. http://nadp.sws.uiuc.edu/.

Ontario Ministry of the Environment (OMOE). 2004. *Air Quality in Ontario 2002 Report*. Queen's Printer for Ontario. http://www.ene.gov.on.ca/envision/techdocs/4521e01.pdf, last accessed June 28, 2004.

Ontario Ministry of the Environment (OMOE). 2003. *Air Quality in Ontario 2001 Report*. Queen's Printer for Ontario. http://www.ene.gov.on.ca/envision/air/AirQuality/2001.htm, last accessed June 17, 2004.

U.S. Environmental Protection Agency (USEPA). 2003a. *1999 National Emissions Inventory Documentation and Data.* http://www.epa.gov/ttn/chief/net/1999inventory.html.

U.S. Environmental Protection Agency (USEPA). 2003b. Clean Air Markets Programs. In *Acid Rain Program: 2002 Progress Report*. EPA-430-R-03-011. http://www.epa.gov/airmarkets/cmprpt/arp02/2002report.pdf, last accessed July 16, 2004.

U.S. Environmental Protection Agency (USEPA). 2003c. *EPA's Draft Report on the Environment: Technical Document*. EPA-600-R-03-050. http://www.epa.gov/indicators/.

U.S. Environmental Protection Agency (USEPA). 2003d. *Latest Findings on National Air Quality: 2002 Status and Trends*. Office of Air Quality Planning and Standards. EPA-454/K-03-001. http://www.epa.gov/airtrends/2002_airtrends_final.pdf, last accessed June 17, 2004.

U.S. Environmental Protection Agency (USEPA). 2003e. *National Air Quality and Emissions Trends Report: 2003 Special Studies Edition*. Office of Air Quality Planning and Standards. EPA-454/R-03-005. http://www.epa.gov/air/airtrends/aqtrnd03/, last accessed June 17, 2004.

U.S. Environmental Protection Agency (USEPA). 2002. *Procedures for developing base year and future year mass and modeling inventories for the heavy-duty engine and vehicle standards and highway diesel fuel (HDD) rulemaking*. EPA420-R-00-020. http://www.epa.gov/otaq/models/hd2007/r00020.pdf, last accessed September 29, 2005.

U.S. Environmental Protection Agency (USEPA). *Clean Air Interstate Rule*. http://www.epa.gov/cair/, last accessed June 8, 2004.

U.S. Environmental Protection Agency (USEPA). *The Clear Skies Initiative*. http://www.epa.gov/clearskies/.

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.

Non-native Species - Aquatic

Indicator #9002 (Aquatic)

Assessment: Poor, Deteriorating (long term)

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, oceangoing ships remain the most-used 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 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 increasingly appreciated, 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

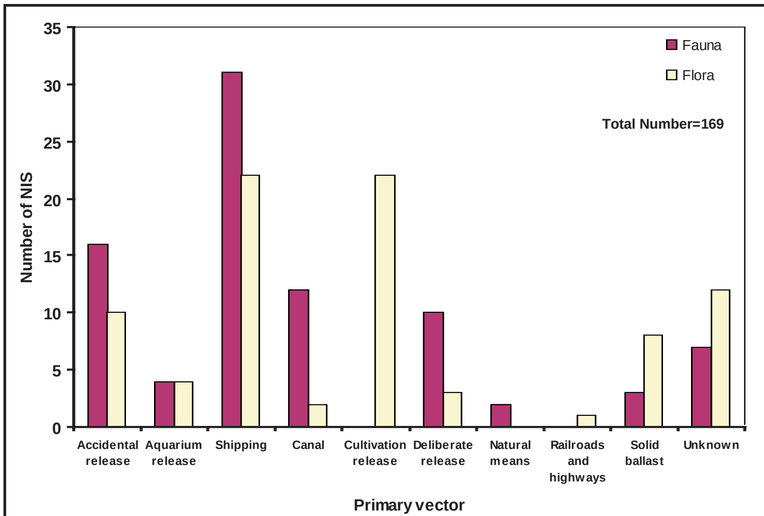

Figure 1. Release mechanisms for aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1830s.
Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003

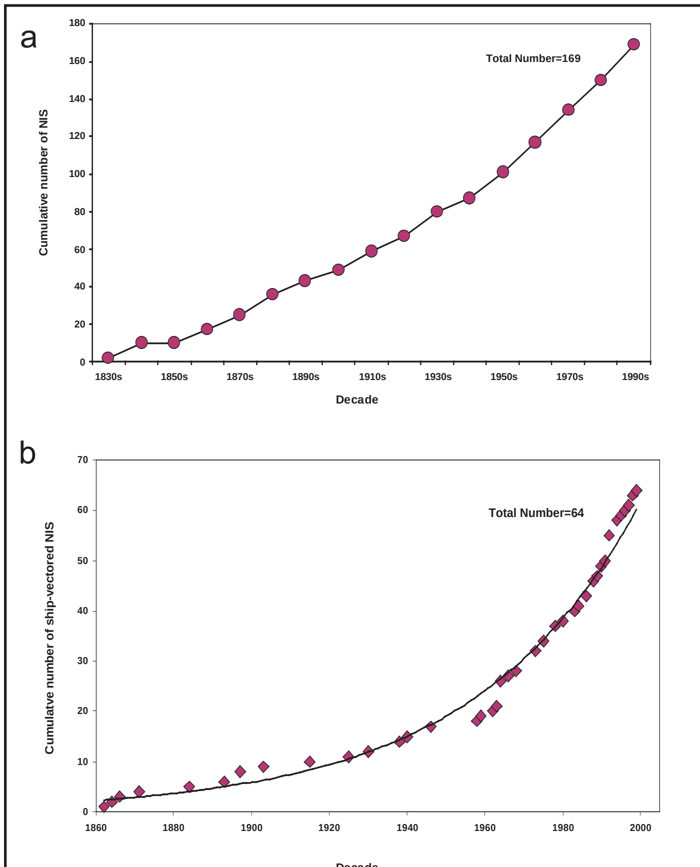

Figure 2. Cumulative number of aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1830s attributed to (a) all vectors and (b) only the ship vector.
Source: Grigorovich *et al.* 2003

Great Lakes' first ballast exchange and management regulations in May of 1993. The National Invasive Species Act followed in 1996.

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, 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; 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*.

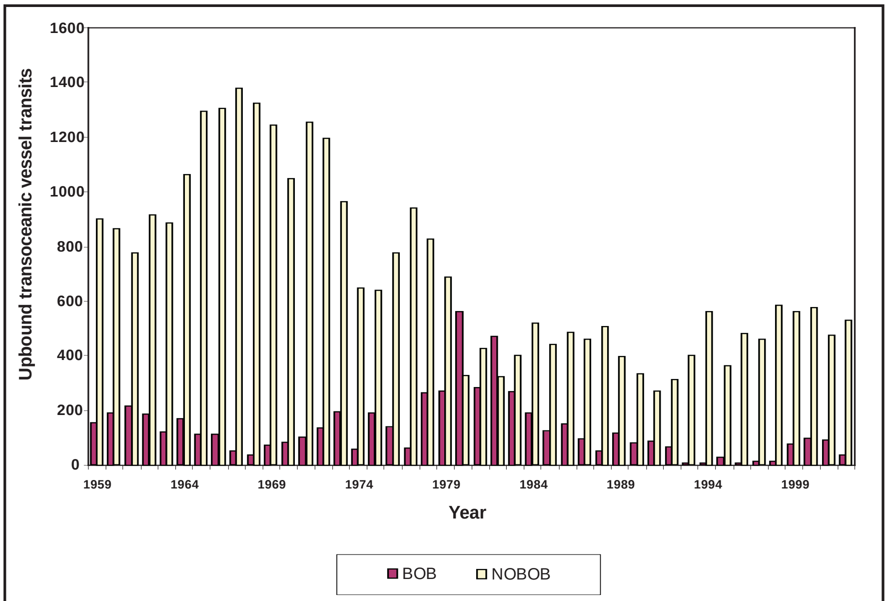

Figure 3. Numbers of upbound transoceanic vessels entering the Great Lakes from 1959 to 2002.
Source: Data from Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003

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 20 miles below an electric barrier in the Chicago Sanitary and Ship Canal, which connects the Mississippi River and the Great Lakes. The electrical dispersal 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) began construction of a second dispersal barrier in 2004. A rotenone treatment plan is being reviewed by Illinois officials for possible deployment should carp threaten to breach the barrier. Barriers and rotenone treatments would not be necessary had there been better screening of species prior to importation. The feasibility of restoring hydrological separation of the Great Lakes and Mississippi River basins is being discussed.

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 foodfish 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. Also, live carp may still be purchased in Montreal. 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

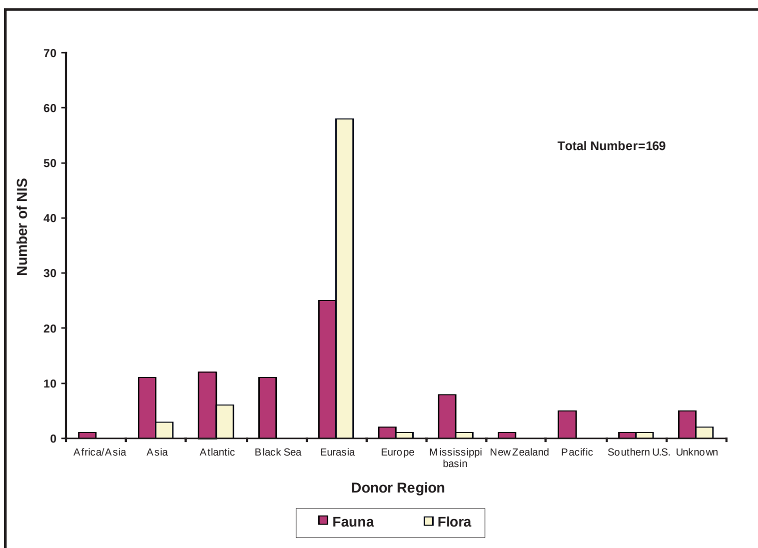

Figure 4. Regions of origin for aquatic NIS established in the Great Lakes basin since the 1830s.
Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003

Species	Reference
Fishes	
Aphanius boyeri	Kolar and Lodge 2002
Benthophilus stellatus	Ricciardi and Rasmussen 1998
Clupeonella caspia (cultriventris)	Ricciardi and Rasmussen 1998; Kolar and Lodge 2002
Hypophthalmichthys (Aristichthys) nobilis	Stokstad 2003; Rixon *et al*. 2004
Hypophthalmichthys molitrix	Stokstad 2003
Misgurnus anguillicaudatus	Rixon *et al*. 2004
Neogobius fluviatilis	Ricciardi and Rasmussen 1998; Kolar and Lodge 2002
Perca fluviatilis	Kolar and Lodge 2002
Phoxinus phoxinus	Kolar and Lodge 2002
Tanichthys albonubes	Rixon *et al*. 2004
Cladocerans	
Daphnia cristata	Grigorovich *et al*. 2003
Bosmina obtusirostris	Grigorovich *et al*. 2003
Cornigerius maeoticus maeoticus	Grigorovich *et al*. 2003
Podonevadne trigona ovum	Grigorovich *et al*. 2003
Copepods	
Heterocope appendiculata	Grigorovich *et al*. 2003
Heterocope caspia	Grigorovich *et al*. 2003
Calanipeda aquae-dulcis	Grigorovich *et al*. 2003
Cyclops kolensis	Grigorovich *et al*. 2003
Ectinosoma abrau	Grigorovich *et al*. 2003
Paraleptastacus spinicaudata triseta	Grigorovich *et al*. 2003
Amphipods	
Corophium curvispinum	Ricciardi and Rasmussen 1998
Corophium sowinskyi	Ricciardi and Rasmussen 1998
Dikerogammarus haemobaphes	Ricciardi and Rasmussen 1998; Grigorovich *et al*. 2003
Dikerogammarus villosus	Ricciardi and Rasmussen 1998; Grigorovich *et al*. 2003
Echinogammarus warpachowskyi	Grigorovich *et al*. 2003
Obesogammarus crassus	Ricciardi and Rasmussen 1998
Pontogammarus aralensis	Grigorovich *et al*. 2003
Pontogammarus obesus	Ricciardi and Rasmussen 1998
Pontogammarus robustoides	Ricciardi and Rasmussen 1998; Grigorovich *et al*. 2003
Mysids	
Hemimysis anomala	Ricciardi and Rasmussen 1998; Grigorovich *et al*. 2003
Limnomysis benedeni	Ricciardi and Rasmussen 1998
Paramysis intermedia	Ricciardi and Rasmussen 1998
Paramysis lacustris	Ricciardi and Rasmussen 1998
Paramysis ullskyi	Ricciardi and Rasmussen 1998
Bivalves	
Hypanys (Monodacna) colorata	Ricciardi and Rasmussen 1998
Polychaetes	
Hypania invalida	Ricciardi and Rasmussen 1998
Plants	
Egeria densa	Rixon *et al*. 2004
Hygrophila polysperma	Rixon *et al*. 2004
Myriophyllum aquaticum	Rixon *et al*. 2004

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

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 foodfish 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 (Figure 4), 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 benefit from the presence of a previously established invader(s) (Ricciardi 2001), i.e., the presence of one non-native species "facilitates" the establishment of another. 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. The present trajectory of NIS reported in the Great Lakes exceeds that observed in earlier years, which, together with an increasing frequency of facilitations, suggests that the system may have already entered an 'invasional meltdown' phase (Ricciardi 2001).

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.

Acknowledgments

Authors: Edward L. Mills, Department of Natural Resources, Cornell University, Bridgeport, NY;
Kristen T. Holeck, Department of Natural Resources, Cornell University, Bridgeport, NY; and
Margaret Dochoda, Great Lakes Fishery Commission, Ann Arbor, MI.

Sources

Alexander, A. 2003. *Legal tools and gaps relating to commerce in exotic live fish: phase 1 report to the Great Lakes Fishery Commission by the Environmental Law and Policy Center.* Environmental Law and Policy Center, Chicago, IL.

Colautti, R.I., Niimi, A.J., van Overdijk, C.D.A., Mills, E.L., Holeck, K.T., and MacIsaac, H.J. 2003. Spatial and temporal analysis of transoceanic shipping vectors to the Great Lakes. In *Invasion Species: Vectors and Management Strategies,* eds. G.M. Ruiz and J.T. Carlton, pp. 227-246. Washington, DC: Island Press.

Grigorovich, I.A., Colautti, R.I., Mills, E.L., Holeck, K.T., Ballert, A.G., and MacIsaac, H.J. 2003. Ballast-mediated animal introductions in the Laurentian Great Lakes: retrospective and prospective analyses. *Can. J. Fish. Aquat. Sci.* 60:740-756.

Holeck, K.T., Mills, E.L., MacIsaac, H.J., Dochoda, M.R., Colautti, R.I., and Ricciardi, A. 2004. Bridging troubled waters: understanding links between biological invasions, transoceanic shipping, and other entry vectors in the Laurentian Great Lakes. *Bioscience* 54:919-929.

Kolar, C.S., and Lodge, D.M. 2002. Ecological predictions and risk assessment for alien fishes in North America. *Science* 298:1233-1236.

Mills, E.L., Leach, J.H., Carlton, J.T., and Secor, C.L. 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. *J. Great Lakes Res.* 19(1):1-54.

Mills, E.L., Scheuerell, M.D., Carlton, J.T., and Strayer, D.L. 1997. Biological invasions in the Hudson River. *NYS Museum* Circular No. 57. Albany, NY.

Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: is an "invasional meltdown" occurring in the Great Lakes? *Can. J. Fish. Aquat. Sci.* 58:2513-2525.

Ricciardi, A., and Rasmussen, J.B. 1998. Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. *Can. J. Fish. Aquat. Sci.* 55:1759-1765.

Rixon, C.A.M., Duggan, I.C., Bergeron, N.M.N., Ricciardi, A., and MacIsaac, H.J. 2004. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. *Biodiversity and Conservation* (in press).

Stokstad, E. 2003. Can well-timed jolts keep out unwanted exotic fish? *Science* 301:157-158.

Williamson, M.H., and Brown, K.C. 1986. The analysis and modeling of British invasions. *Philosophical Transactions of the Royal Society of London, Series B.* 314:505-522.

Non-native Species - Terrestrial

Indicator #9002

Note: This is a progress report towards implementing this indicator.

Assessment: Not Assessed

Purpose

- To assess the presence, number and distribution of terrestrial nonindigenous species (NIS) in the Laurentian Great Lakes basin; 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

Only a small percentage of non-native species introduced into the ecosystem, primarily through human activity, pose a hazard to the economy, environment or human health. However, the lack of naturally-occurring predators allows some non-native species to become invasive by colonizing and proliferating unchecked. This destroys wildlife habitats, crowds out competitors and depletes prey, thereby threatening biodiversity.

Once established, terrestrial non-native species can also impact water quality, by changing water tables, runoff dynamics, fire frequency, and other watershed attributes that in turn can alter watershed conditions. Attempts to eradicate terrestrial non-native species could lead to greater use of pesticides and herbicides, in turn potentially increasing the amount of chemicals entering surface water through runoff.

State of the Ecosystem

The negative impact of a wide range of non-native species, such as reed canary grass, garlic mustard, common buckthorn and purple loosestrife, has been documented throughout the Great Lakes basin. However, the extent of invasion by terrestrial non-native species is not known. It is not clear what metric should be used to report on this indicator.

Federal and state agencies, tribal governments, nongovernmental organizations, and universities are actively collecting data on terrestrial non-native species. At this point, most projects focus on a single species on a local basis. Projects range from mapping where non-native species have been detected in a given jurisdiction, to measuring the actual population or extent of area covered by that species. This large body of research presents an opportunity to increase our understanding of the problem posed by terrestrial non-native species. Coordination of these data collection efforts may produce the comprehensive data necessary for assessment, not to mention monitoring, control and eradication.

Future Pressures

Growth in international trade and travel increases the risk that a larger number of terrestrial non-native species will become established in the Great Lakes region. The spread of microbes such as the West Nile virus and the SARS virus demonstrates the speed and ease in which non-native species can migrate on a global basis. Response efforts vary by species. It is believed that terrestrial non-native species that do not pose an immediate threat to agriculture, industry or human health may not prompt sufficient response to mitigate their impacts to the ecosystem.

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5.0 Complete List of Indicators in Great Lakes Suite, Organized by Categories

ID #	Indicator Name	2005 Assessment (Status, Trend)	2003 Assessment	2001 Assessment
CONTAMINATION				
Nutrients				
111	Phosphorus Concentrations and Loadings	Mixed, Undetermined	Mixed	Mixed
4860	*Phosphorus and Nitrogen Levels (Coastal Wetlands)*			
7061	Nutrient Management Plans	N/A	N/A	
Toxics in Biota				
114	Contaminants in Young-of-the-Year Spottail Shiners	Mixed, Improving	Mixed Improving	
115	Contaminants in Colonial Nesting Waterbirds	Mixed, Improving	Mixed Improving	Good
121	Contaminants in Whole Fish	Mixed, Improving	N/A	
124	External Anomaly Prevalence Index for Nearshore Fish	Poor-Mixed, Undetermined	N/A (#101)	
4177	Biologic Markers of Human Exposure to Persistent Chemicals	Mixed, Undetermined		
4201	Contaminants in Sport Fish	Mixed, Improving	Mixed Improving (#4083)	Mixed Improving(#4083)
4506	Contaminants in Snapping Turtle Eggs	Mixed, N/A	Mixed	Mixed
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, Improving	Mixed Improving	Mixed Improving
8147	Population Monitoring and Contaminants Affecting the American Otter	(2003 report)	Mixed	N/A
Toxics in Media				
117	Atmospheric Deposition of Toxic Chemicals	Mixed, Improving & Mixed, Unchanging	Mixed	Mixed Improving
118	Toxic Chemical Concentrations in Offshore Waters	Mixed, Improving	Mixed Improving	Mixed
119	Concentrations of Contaminants in Sediment Cores	Mixed, Improving	Mixed Improving	
4175	Drinking Water Quality	Good, Unchanging	Good	Good
4202	Air Quality	Mixed, Improving	Mixed (#4176)	Mixed (#4176)
9000	Acid Rain	Mixed, Improving	Mixed Improving	Mixed
Sources and Loadings				
117	Atmospheric Deposition of Toxic Chemicals	Mixed, Improving & Mixed, Unchanging	Mixed	Mixed Improving
4202	Air Quality	Mixed, Improving	Mixed (#4176)	Mixed (#4176)
9000	Acid Rain	Mixed, Improving	Mixed Improving	Mixed
BIOTIC COMMUNITIES				
Fish				
8	Salmon and Trout	Mixed, Improving	Mixed	
9	Walleye	Good, Unchanging	Mixed	Good
17	Preyfish Populations	Mixed, Deteriorating & Mixed, Improving	Mixed Deteriorating	Mixed Improving
93	Lake Trout	Mixed, Improving & Mixed, Unchanging	Mixed	Mixed
125	Status of Lake Sturgeon in the Great Lakes	Mixed, Undetermined	N/A	
4502	Coastal Wetland Fish Community Health	N/A		

N/A = Not Assessed
Number in bracket indicates related indicator
Italics indicate no report for that indicator

BIOTIC COMMUNITIES (con'd)				
Birds				
115	Contaminants in Colonial Nesting Waterbirds	Mixed, Improving	Mixed Improving	Good
4507	Wetland-Dependent Bird Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, Improving	Mixed Improving	Mixed Improving
8150	*Breeding Bird Diversity and Abundance*			
Mammals				
8147	Population Monitoring and Contaminants Affecting the American Otter	(2003 report)	Mixed	N/A
Amphibians				
4504	Coastal Wetland Amphibian Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
7103	Groundwater Dependant Plant and Animal Communities	N/A		
Invertebrates				
68	Native Freshwater Mussels	N/A	N/A	Mixed Deteriorating
104	Benthos Diversity and Abundance - Aquatic Oligochaete Communities	(2003 report)	Mixed	
116	Zooplankon Populations	(2003 report)	N/A	Mixed
122	*Hexagenia*	Mixed, Improving	Mixed Improving	Mixed Improving
123	Abundances of the Benthic Amphipod *Diporeia* spp.	Mixed, Deteriorating	Mixed Deteriorating	Mixed
4501	Coastal Wetland Invertebrate Community Health	N/A		
Plants				
109	Phytoplankton Populations	(2003 report)	Mixed	Mixed
4862	Coastal Wetland Plant Community Health	Mixed, Undetermined		
8162	*Health of Terrestrial Plant Communities*			
8500	Forest Lands - Conservation of Biological Diversity	Mixed, Improving		
General				
8114	*Habitat Fragmentation*			
8137	*Nearshore Species Diversity and Stability*			
8161	*Threatened Species*			
8163	*Status and Protection of Special Places and Species*			
INVASIVE SPECIES				
Aquatic				
18	Sea Lamprey	Good-Fair, Improving	Mixed Improving	Mixed
9002	Non-Native Species (Aquatic)	Poor, Deteriorating	Poor	Poor
Terrestrial				
9002	*Non-Native Species (Terrestrial)*			

COASTAL ZONES				
Nearshore Aquatic				
6	*Fish Habitat*			
4860	*Phosphorus and Nitrogen Levels (Coastal Wetlands)*			
4861	Effect of Water Levels Fluctuations	(2003 report)	Mixed	Mixed Deteriorating
4864	*Human Impact Measures (Coastal Wetlands)*			
8131	Extent of Hardened Shoreline	(2001 report)	(2001 report)	Mixed Deteriorating
8142	*Sediment Available for Coastal Nourishment*			
8146	*Artificial Coastal Structures*			
Coastal Wetlands				
4501	Coastal Wetland Invertebrate Community Health	N/A		
4502	Coastal Wetland Fish Community Health	N/A		
4504	Coastal Wetland Amphibian Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
4506	Contaminants in Snapping Turtle Eggs	Mixed, N/A	Mixed	Mixed
4507	Wetland-Dependent Bird Diversity and Abundance	Mixed, Deteriorating	Mixed Deteriorating	Mixed Deteriorating
4510	Coastal Wetland Area by Type	Mixed, Deteriorating	(2001 report)	Mixed Deteriorating
4511	*Coastal Wetland Restored Area by Type*			
4516	*Sediment Flowing into Coastal Wetlands*			
4860	*Phosphorus and Nitrogen Levels*			
4861	Effects of Water Levels Fluctuations	(2003 report)	Mixed	Mixed Deteriorating
4862	Coastal Wetland Plant Community Health	Mixed, Undetermined		
4863	*Land Use Adjacent to Wetlands*			
4864	*Human Impact Measures*			
8142	*Sediment Available for Coastal Nourishment*			
Terrestrial				
4861	Effects of Water Levels Fluctuations	(2003 report)	Mixed	Mixed Deteriorating
4864	*Human Impact Measures (Coastal Wetlands)*			
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	(2001 report)	(2001 report)	Mixed
8129	*Area, Quality, and Protection of Special Lakeshore Communities - Islands*			
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	Mixed, Deteriorating		
8129	*Area, Quality, and Protection of Special Lakeshore Communities - Sand Dunes*			
8131	Extent of Hardened Shoreline	(2001 report)	(2001 report)	Mixed Deteriorating
8132	*Nearshore Land Use*			
8136	*Extent and Quality of Nearshore Natural Land Cover*			
8137	*Nearshore Species Diversity and Stability*			
8142	*Sediment Available for Coastal Nourishment*			
8149	*Protected Nearshore Areas*			

AQUATIC HABITATS				
Open Lake				
6	*Fish Habitat*			
111	Phosphorus Concentrations and Loadings	Mixed	Mixed	Mixed
118	Toxic Chemical Concentrations in Offshore Waters	Mixed, Improving	Mixed Improving	Mixed
119	Concentrations of Contaminants in Sediment Cores	Mixed, Improving	Mixed Improving	
8131	Extent of Hardened Shoreline	(2001 report)	(2001 report)	Mixed Deteriorating
8142	*Sediment Available for Coastal Nourishment*			
8146	*Artificial Coastal Structures*			
Groundwater				
7100	Natural Groundwater Quality and Human-Induced Changes	N/A	N/A	
7101	Groundwater and Land: Use and Intensity	N/A	N/A	
7102	Base Flow Due to Groundwater Discharge	Mixed, Deteriorating	N/A	
7103	Groundwater Dependant Plant and Animal Communities	N/A		
HUMAN HEALTH				
4175	Drinking Water Quality	Good, Unchanging	Good	Good
4177	Biologic Markers of Human Exposure to Persistent Chemicals	Mixed, Undetermined		
4179	*Geographic Patterns and Trends in Disease Incidence*			
4200	Beach Advisories, Postings and Closures	Mixed, Undetermined	Mixed (#4081)	Mixed (#4081)
4201	Contaminants in Sport Fish	Mixed, Improving	Mixed Improving (#4083)	Mixed Improving (#4083)
4202	Air Quality	Mixed, Improving	Mixed (#4176)	Mixed (#4176)
LAND USE - LAND COVER				
General				
4863	*Land Use Adjacent to Wetlands (Coastal Wetlands)*			
7002	Land Cover / Land Conversion	N/A		
7101	Groundwater and Land: Use and Intensity	N/A	N/A	
8114	*Habitat Fragmentation*			
8132	*Nearshore Land Use*			
8136	*Extent and Quality of Nearshore Natural Land Cover*			
Forest Lands				
8500	Forest Lands-Conservation of Biological Diversity	Mixed, Improving		
8501	*Maintenance and Productive Capacity of Forest Ecosystems*			
8502	*Maintenance of Forest Ecosystem Health and Vitality*			
8503	*Forest Lands-Conservation & Maintenance of Soil & Water Resources*			
Agricultural Lands				
7028	Sustainable Agriculture Practices	N/A	N/A	Mixed
7061	Nutrient Management Plans	N/A		
7062	Integrated Pest Management	N/A		

LAND USE - LAND COVER (con'd)				
Urban/Suburban Lands				
7000	Urban Density	Mixed, N/A	Mixed Deteriorating	Unable to Assess
7006	Brownfields Redevelopment	(2003 report)	Mixed Improving	Mixed Improving
7054	*Ground Surface Hardening*			
Protected Areas				
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	(2001 report)	(2001 report)	Mixed
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	Mixed, Deteriorating		
8129	*Area, Quality, and Protection of Special Lakeshore Communities - Islands*			
8129	*Area, Quality, and Protection of Special Lakeshore Communities - Sand Dunes*			
8149	*Protected Nearshore Areas*			
8163	*Status and Protection of Special Places and Species*			
RESOURCE UTILIZATION				
3514	Commercial/Industrial Eco-Efficiency Measures	(2003 report)	N/A	
3516	*Household Stormwater Recycling*			
7043	Economic Prosperity	(2003 report)	Mixed (L. Superior basin)	Mixed
7056	Water Withdrawals	Mixed, Unchanging		
7057	Energy Consumption	Mixed, N/A	Mixed Deteriorating	
7060	Solid Waste Generation	(2003 report)	Mixed	
7064	*Vehicle Use*			
CLIMATE CHANGE				
4858	Climate Change: Ice Duration on the Great Lakes	(2003 report)	Mixed Deteriorating	
9003	*Climate Change: Effect on Crop Heat Units*			

N/A = Not Assessed
Number in bracket indicates related indicator
Italics indicate no report for that indicator

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
µg/m^3	microgram per cubic metre
µm	micrometer, micron, 10^{-6} metre

Chemicals

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	Topologically 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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Region 5
U.S. Fish and Wildlife Service
Alpena Fishery Resources Office
Ashland Fishery Resources Office
East Lansing Ecological Services Office
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Provincial and State
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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