State of the Great Lakes

2009

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State of the Great Lakes 2009

by the Governments of
Canada
and the
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 about the Great Lakes basin ecosystem through the State of the Great Lakes reporting process. The work is undertaken in accordance with the Great Lakes Water Quality Agreement, and is integral to the mission to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes basin ecosystem. Knowing the environmental condition of the Great Lakes can allow for effective decision-making by all Great Lakes stakeholders.

The information in this report, **State of the Great Lakes 2009**, has been assembled from various sources with the participation of many people from throughout the Great Lakes scientific community. The data are based on indicator reports and presentations from the State of the Lakes Ecosystem Conference (SOLEC), held in Niagara Falls, Ontario, October 22-23, 2008.

SOLEC and the subsequent reports provide independent, science-based reporting on the state of the health of the Great Lakes basin ecosystem. Four objectives for the SOLEC process include:

- To assess the state of the Great Lakes ecosystem based on accepted indicators
- To strengthen decision-making and environmental management concerning the Great Lakes
- To inform local decision makers of Great Lakes environmental issues
- To provide a forum for communication and networking amongst all the Great Lakes stakeholders

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

The current information about Great Lakes ecosystem and human health is presented in several levels of detail, in both print and electronic formats.

State of the Great Lakes 2009. This technical report contains the full indicator reports as prepared by the primary authors, the indicator category assessments, and management challenges. It also contains detailed references to data sources.

State of the Great Lakes 2009 Highlights. This report highlights key information presented in the main report.

Nearshore Areas of the Great Lakes 2009. This report provides a comprehensive summary of current environmental conditions of the nearshore areas of the Great Lakes. The report examines various components of the nearshore area, documents changes since 1996, and identifies management challenges.

State of the Great Lakes Summary Series. These summaries, prepared in 2007, provide information about a variety of indicators and issues such as: the quality of drinking water, swimming at the beaches, eating Great Lakes fish, air quality, aquatic invasive species, amphibians, birds, forests, coastal wetlands, the Great Lakes food web and special places such as islands, alvars and cobble beaches. In addition there is a summary for each of the Great Lakes, plus the St. Clair-Detroit River ecosystem and the St. Lawrence River.

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

1.0 Introduction

This **State of the Great Lakes 2009** report presents the compilation, scientific analysis and interpretation of data about the Great Lakes basin ecosystem. It represents the combined efforts of many scientists and managers in the Great Lakes community representing federal, Tribal/First Nations, state, provincial and municipal governments, non-government organizations, industry, academia and private citizens.

The eighth in a series of reports beginning in 1995, the **State of the Great Lakes 2009** 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 United States in response to requirements of the Great Lakes Water Quality Agreement (GLWQA) for regular reporting on progress toward Agreement goals and objectives. Since the first conference in 1994, SOLEC has evolved into a two-year cycle[1] of data collection, assessment and reporting on conditions and the major pressures in the Great Lakes basin. The year following each conference, a State of the Great Lakes report is prepared, based on information presented and discussed at the conference and post-conference comments. Additional information about SOLEC and the Great Lakes indicators is available at www.binational.net and http://epa.gov/glnpo/solec/index.html.

The **State of the Great Lakes 2009** provides assessments of 62 of approximately 80 ecosystem indicators and overall assessments of the categories into which the indicators are grouped: Contamination, Human Health, Biotic Communities, Invasive Species, Coastal Zones and Aquatic Habitats, Resource Utilization, Land Use-Land Cover, and Climate Change. Within most of the main categories are sub-categories to further delineate issues or geographic areas.

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

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

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

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

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

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

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

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

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

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

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

1 In 2011, SOLEC will begin a three-year reporting cycle

Each indicator report is supported by scientific information collected and assessed by Great Lakes experts from Canada and the United States, along with a review of scientific papers and use of best professional judgment. For many indicators, ecosystem objectives, endpoints, or benchmarks have not been established. For these indicators, complete assessments are difficult to determine. Overall assessments and management challenges were also prepared for each category to the extent that indicator information was available.

For 2009, the overall status of the Great Lakes ecosystem was assessed as *mixed* because some conditions or areas were *good* while others were *poor*. The trends of Great Lakes ecosystem conditions varied: some conditions were *improving* and some were *worsening*.

Some of the good features of the ecosystem leading to the mixed conclusion include:

- Levels of most contaminants in herring gull eggs and predator fish continue to decrease.
- Phosphorus concentrations in the open waters are at or below expected levels in Lake Ontario, Lake Huron, Lake Michigan and Lake Superior.
- The Great Lakes are a good source for treated drinking water.
- Sustainable forestry programs throughout the Great Lakes basin are helping environmentally friendly management practices.
- Lake trout stocks in Lake Superior have remained self-sustaining, and some natural reproduction of lake trout is occurring in Lake Ontario, Lake Huron and Lake Michigan.
- Confirmed observations and captures of lake sturgeon are increasing in all lakes.
- Mayfly (*Hexagenia*) populations are recovering in some areas.
- The Great Lakes bald eagle population is on the rebound and it has been removed from protection under the U.S. Endangered Species Act.

Some of the negative features of the ecosystem leading to the mixed conclusion include:

- Perfluoroctanesulfonate (PFOS), which is a product used in surfactants such as water-repellent coatings and fire-suppressing foams, has been detected in fish throughout the Great Lakes and has demonstrated the capacity for biomagnification in food webs.
- Nuisance growth of the green alga *Cladophora* has reappeared along the shoreline in many places.
- Many nearshore areas are experiencing elevated levels of phosphorus, which is contributing to nuisance algae growth.
- Non-native species (aquatic and terrestrial) are pervasive throughout the Great Lakes basin, and they continue to exert impacts on native species and communities.
- Populations of *Diporeia*, the once-dominant, native, bottom-dwelling invertebrate, continue to decline in Lake Michigan, Lake Huron, and Lake Ontario, and they may be extinct in Lake Erie.
- Groundwater withdrawals for municipal water supplies and irrigation, and the increased proportion of impervious surfaces in urban areas, have negatively impacted groundwater.
- Long range atmospheric transport is a continuing source of PCBs and other contaminants to the Great Lakes basin, and can be expected to be significant for decades.
- Land use changes in favor 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.

A complete list of the Great Lakes indicators in the SOLEC suite is provided in the following table, which is organized by indicator categories. Also included in this table are the 2009 indicator assessments for the **State of the Great Lakes 2009** indicator reports with previous assessments from 2007, 2005, and 2003 where available.

ID #	Indicator Name	2009 Assessment (Status, Trend)	2007 Assessment (Status, Trend)	2005 Assessment (Status, Trend)	2003 Assessment
CONTAMINATION					
Nutrients					
111	Phosphorus Concentrations and Loadings	Open Lake: Mixed, Mixed (Improving or Unchanging) Nearshore: Poor, Undetermined	Open Lake: Mixed, Undetermined Nearshore: Poor, Undetermined	Mixed, Undetermined	Mixed
4860	*Phosphorus and Nitrogen Levels (Coastal Wetlands)*				
7061	Nutrient Management Plans	N/A, Undetermined (2005 report)	N/A (2005 report)	N/A	N/A
Toxics in Biota					
114	Contaminants in Young-of-the-Year Spottail Shiners	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed, Improving
115	Contaminants in Colonial Nesting Waterbirds	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed, Improving
121	Contaminants in Whole Fish	Mixed, Improving	Mixed, Improving	Mixed, Improving	N/A
124	External Anomaly Prevalence Index for Nearshore Fish	Poor, Unchanging (2007 Report)	Poor, Unchanging	Poor-Mixed, Undetermined	N/A (#101)
4177	Biologic Markers of Human Exposure to Persistent Chemicals	N/A, Undetermined (2007 Report)	N/A, Undetermined	Mixed, Undetermined	
4201	Contaminants in Sport Fish	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed, Improving (#4083)
4506	Contaminants in Snapping Turtle Eggs	Mixed, Undetermined (2007 Report)	Mixed, Undetermined	Mixed, N/A	Mixed
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, Improving (2005 report)	Mixed, Improving (2005 report)	Mixed, Improving	Mixed, Improving
8147	Population Monitoring and Contaminants Affecting the American Otter	Mixed, Undetermined (2003 report)	Mixed, Undetermined (2003 report)	Mixed, Undetermined (2003 report)	Mixed
Toxics in Media					
117	Atmospheric Deposition of Toxic Chemicals	Mixed, Improving & Mixed, Unchanging/ Slightly Improving	Mixed, Improving & Mixed, Unchanging/ Improving	Mixed, Improving & Mixed, Unchanging	Mixed
118	Toxic Chemical Concentrations in Offshore Waters	Mixed, Undetermined	Mixed, Undetermined	Mixed, Improving	Mixed, Improving
119	Concentrations of Contaminants in Sediment Cores	Mixed, Improving/ Undetermined	Mixed, Improving/ Undetermined	Mixed, Improving	Mixed, Improving
4175	Drinking Water Quality	Good, Unchanging	Good, Unchanging	Good, Unchanging	Good
4202	Air Quality	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed (#4176)
9000	Acid Rain	Mixed, Improving	Mixed, Improving (2005 report)	Mixed, Improving	Mixed, Improving

N/A = Not Assessed; Number in brackets indicates related indicator; Reports are currently unavailable for the indicators in italics.

ID #	Indicator Name	2009 Assessment (Status, Trend)	2007 Assessment (Status, Trend)	2005 Assessment (Status, Trend)	2003 Assessment
Sources and Loadings					
117	Atmospheric Deposition of Toxic Chemicals	Mixed, Improving & Mixed, Unchanging/ Slightly Improving	Mixed, Improving & Mixed, Unchanging/ Improving	Mixed, Improving & Mixed, Unchanging	Mixed
4202	Air Quality	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed (#4176)
7065	Wastewater Treatment and Pollution	N/A, Undetermined Progress Report	N/A Progress Report		
9000	Acid Rain	Mixed, Improving	Mixed, Improving (2005 report)	Mixed, Improving	Mixed, Improving
BIOTIC COMMUNITIES					
Fish					
8	Salmon and Trout	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed
9	Walleye	Mixed, Undetermined	Fair, Unchanging	Good, Unchanging	Mixed
17	Preyfish Populations	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating & Mixed, Improving	Mixed, Deteriorating
93	Lake Trout	Mixed, Unchanging	Mixed, Unchanging	Mixed, Improving & Mixed, Unchanging	Mixed
125	Status of Lake Sturgeon in the Great Lakes	Mixed, Improving	Mixed, Improving	Mixed, Undetermined	N/A
4502	Coastal Wetland Fish Community Health	N/A Progress Report	N/A Progress Report	N/A	
Birds					
115	Contaminants in Colonial Nesting Waterbirds	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed, Improving
4507	Wetland-Dependent Bird Diversity and Abundance	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating
8135	Contaminants Affecting Productivity of Bald Eagles	Mixed, Improving (2005 report)	Mixed, Improving (2005 report)	Mixed, Improving	Mixed, Improving
8150	*Breeding Bird Diversity and Abundance*				
Mammals					
8147	Population Monitoring and Contaminants Affecting the American Otter	Mixed, Undetermined (2003 report)	Mixed, Undetermined (2003 report)	Mixed, Undetermined (2003 report)	Mixed
Amphibians					
4504	Coastal Wetland Amphibian Diversity and Abundance	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating
7103	Groundwater Dependant Plant and Animal Communities	N/A	N/A (2005 report)	N/A	
Invertebrates					
68	Native Freshwater Mussels	N/A	N/A (2005 report)	N/A	N/A
104	Benthos Diversity and Abundance - Aquatic Oligochaete Communities	Mixed, Unchanging/ Deteriorating	Mixed, Unchanging/ Deteriorating	Mixed, Undetermined (2003 report)	Mixed

N/A = Not Assessed; Number in brackets indicates related indicator; Reports are currently unavailable for the indicators in italics.

ID #	Indicator Name	2009 Assessment (Status, Trend)	2007 Assessment (Status, Trend)	2005 Assessment (Status, Trend)	2003 Assessment
116	Zooplankon Populations	Mixed, Undetermined	Mixed, Undetermined	N/A (2003 report)	N/A
122	Hexagenia	Mixed, Mixed to Improving	Mixed, Improving	Mixed, Improving	Mixed, Improving
123	Abundances of the Benthic Amphipod Diporeia spp.	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating
4501	Coastal Wetland Invertebrate Community Health	N/A Progress Report	N/A (2005 Progress Report)	N/A Progress Report	
Plants					
109	Phytoplankton Populations	Mixed, Undetermined (2003 report)	Mixed, Undetermined (2003 report)	Mixed, Undetermined (2003 report)	Mixed
4862	Coastal Wetland Plant Community Health	Mixed, Undetermined	Mixed, Undetermined	Mixed, Undetermined	
8162	*Health of Terrestrial Plant Communities*				
8500	Forest Lands - Conservation of Biological Diversity	Mixed, Undetermined	Mixed, Undetermined	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	Fair, Mixed	Good-Fair, Improving (2005 Report)	Good-Fair, Improving	Mixed, Improving
9002	Non-Native Species (Aquatic)	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating	Poor
Terrestrial					
9002	Non-Native Species (Terrestrial)	N/A, Undetermined (2007 Report)	N/A, Undetermined		
COASTAL ZONES					
Nearshore Aquatic					
6	*Fish Habitat*				
4860	*Phosphorus and Nitrogen Levels (Coastal Wetlands)*				
4861	Effects of Water Level Fluctuations	Mixed, Undetermined	Mixed, Undetermined (2003 Report)	Mixed, Undetermined (2003 Report)	Mixed
4864	*Human Impact Measures (Coastal Wetlands)*				

N/A = Not Assessed; Number in brackets indicates related indicator; Reports are currently unavailable for the indicators in italics.

ID #	Indicator Name	2009 Assessment (Status, Trend)	2007 Assessment (Status, Trend)	2005 Assessment (Status, Trend)	2003 Assessment
8131	Extent of Hardened Shoreline	Mixed, Deteriorating	Mixed, Deteriorating (2001 Report)	Mixed, Deteriorating (2001 Report)	Mixed, Deteriorating (2001 Report)
8142	*Sediment Available for Coastal Nourishment*				
8146	*Artificial Coastal Structures*				
Coastal Wetlands					
4501	Coastal Wetland Invertebrate Community Health	N/A Progress Report	N/A (2005 Progress Report)	N/A Progress Report	
4502	Coastal Wetland Fish Community Health	N/A Progress Report	N/A Progress Report	N/A	
4504	Coastal Wetland Amphibian Diversity and Abundance	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating
4506	Contaminants in Snapping Turtle Eggs	Mixed, Undetermined	Mixed, Undetermined	Mixed, Undetermined	Mixed
4507	Wetland-Dependent Bird Diversity and Abundance	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating
4510	Coastal Wetland Area by Type	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating	Mixed Deteriorating (2001 Report)
4511	*Coastal Wetland Restored Area by Type*				
4516	*Sediment Flowing into Coastal Wetlands*				
4860	*Phosphorus and Nitrogen Levels*				
4861	Effects of Water Level Fluctuations	Mixed, Undetermined	Mixed, Undetermined (2003 Report)	Mixed, Undetermined (2003 Report)	Mixed
4862	Coastal Wetland Plant Community Health	Mixed, Undetermined	Mixed, Undetermined	Mixed, Undetermined	
4863	Land Cover Adjacent to Coastal Wetlands	Not Fully Assessed, Undetermined (2007 Progress Report)	N/A Progress Report		
4864	*Human Impact Measures*				
8142	*Sediment Available for Coastal Nourishment*				
Terrestrial					
4861	Effects of Water Level Fluctuations	Mixed, Undetermined	Mixed, Undetermined (2003 Report)	Mixed, Undetermined (2003 Report)	Mixed
4864	*Human Impact Measures (Coastal Wetlands)*				
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	Mixed, Undetermined (2001 Report)	Mixed, Undetermined (2001 Report)	Mixed, Undetermined (2001 Report)	Mixed (2001 Report)
8129	Area, Quality, and Protection of Special Lakeshore Communities - Islands	Mixed, Undetermined	Mixed, Undetermined		

N/A = Not Assessed; Number in brackets indicates related indicator; Reports are currently unavailable for the indicators in italics.

ID #	Indicator Name	2009 Assessment (Status, Trend)	2007 Assessment (Status, Trend)	2005 Assessment (Status, Trend)	2003 Assessment
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	Mixed, Deteriorating (2005 Report)	Mixed, Deteriorating (2005 Report)	Mixed, Deteriorating	
8129	Area, Quality, and Protection of Special Lakeshore Communities - Sand Dunes	N/A, Undetermined	N/A, Undetermined (2005 Progress Report)	N/A, Undetermined Progress Report	
8131	Extent of Hardened Shoreline	Mixed, Deteriorating	Mixed, Deteriorating (2001 Report)	Mixed, Deteriorating (2001 Report)	Mixed, Deteriorating (2001 Report)
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	Open Lake: Mixed, Mixed (Improving or Unchanging) Nearshore: Poor, Undetermined	Open Lake:Mixed, Undetermined Nearshore: Poor, Undetermined	Mixed	Mixed
118	Toxic Chemical Concentrations in Offshore Waters	Mixed, Undetermined	Mixed, Improving	Mixed, Improving	Mixed, Improving
119	Concentrations of Contaminants in Sediment Cores	Mixed, Improving/ Undetermined	Mixed, Improving/ Undetermined	Mixed, Improving	Mixed, Improving
8131	Extent of Hardened Shoreline	Mixed, Deteriorating	Mixed, Deteriorating (2001 Report)	Mixed, Deteriorating (2001 Report)	Mixed, Deteriorating (2001 Report)
8142	*Sediment Available for Coastal Nourishment*				
8146	*Artificial Coastal Structures*				
Groundwater					
7100	Natural Groundwater Quality and Human-Induced Changes	N/A	N/A (2005 Report)	N/A	N/A
7101	Groundwater and Land: Use and Intensity	N/A, Undetermined	N/A (2005 Report)	N/A	N/A
7102	Base Flow Due to Groundwater Discharge	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating	N/A
7103	Groundwater Dependant Plant and Animal Communities	N/A, Undetermined	N/A (2005 Report)	N/A	
HUMAN HEALTH					
4175	Drinking Water Quality	Good, Unchanging	Good, Unchanging	Good, Unchanging	Good
N/A = Not Assessed; Number in brackets indicates related indicator; Reports are currently unavailable for the indicators in italics.					

ID #	Indicator Name	2009 Assessment (Status, Trend)	2007 Assessment (Status, Trend)	2005 Assessment (Status, Trend)	2003 Assessment
4177	Biologic Markers of Human Exposure to Persistent Chemicals	N/A, Undetermined (2007 Report)	N/A, Undetermined	Mixed, Undetermined	
4179	*Geographic Patterns and Trends in Disease Incidence*				
4200	Beach Advisories, Postings and Closures	Mixed, Unchanging	Mixed, Undetermined	Mixed, Undetermined	Mixed (#4081)
4201	Contaminants in Sport Fish	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed, Improving (#4083)
4202	Air Quality	Mixed, Improving	Mixed, Improving	Mixed, Improving	Mixed (#4176)
LAND USE - LAND COVER					
General					
4863	Land Cover Adjacent to Coastal Wetlands	Not Fully Assessed, Undetermined (2007 Progress Report)	N/A Progress Report		
7002	Land Cover - Land Conversion	Mixed, Undetermined (2007 Report)	Mixed, Undetermined	N/A	
7101	Groundwater and Land: Use and Intensity	N/A, Undetermined	N/A (2005 Report)	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, Undetermined	Mixed, Undetermined	Mixed, Improving	
8501	Forest Lands - Maintenance and Productive Capacity of Forest Ecosystems	N/A, Undetermined	N/A, Undetermined		
8502	*Maintenance of Forest Ecosystem Health and Vitality*				
8503	Forest Lands - Conservation & Maintenance of Soil & Water Resources	Mixed, Undetermined/ Improving	Mixed, Undetermined		
Agricultural Lands					
7028	Sustainable Agriculture Practices	N/A (2005 Report)	N/A (2005 Report)	N/A	N/A
7061	Nutrient Management Plans	N/A (2005 Report)	N/A (2005 Report)	N/A	
7062	Integrated Pest Management	N/A (2005 Report)	N/A (2005 Report)	N/A	
Urban/Suburban Lands					
7000	Urban Density	Mixed, Undetermined	Mixed, Undetermined	Mixed, Undetermined	Mixed, Deteriorating
7006	Brownfields Redevelopment	Mixed, Improving	Mixed, Improving	Mixed, Improving (2003 Report)	Mixed, Improving
N/A = Not Assessed; Number in brackets indicates related indicator; Reports are currently unavailable for the indicators in italics.					

ID #	Indicator Name	2009 Assessment (Status, Trend)	2007 Assessment (Status, Trend)	2005 Assessment (Status, Trend)	2003 Assessment
7054	Ground Surface Hardening	Fair, Undetermined	N/A (2005 Progress Report)	N/A Progress Report	
Protected Areas					
8129	Area, Quality, and Protection of Special Lakeshore Communities - Alvars	Mixed, Undetermined (2001 Report)	Mixed, Undetermined (2001 Report)	Mixed, Undetermined (2001 Report)	Mixed (2001 Report)
8129	Area, Quality, and Protection of Special Lakeshore Communities - Islands	Mixed, Undetermined	Mixed, Undetermined		
8129	Area, Quality, and Protection of Special Lakeshore Communities - Cobble Beaches	Mixed, Deteriorating (2005 Report)	Mixed, Deteriorating (2005 Report)	Mixed, Deteriorating	
8129	Area, Quality, and Protection of Special Lakeshore Communities - Sand Dunes	N/A, Undetermined	N/A, Undetermined (2005 Progress Report)	N/A, Undetermined Progress Report	
8149	*Protected Nearshore Areas*				
8163	*Status and Protection of Special Places and Species*				
RESOURCE UTILIZATION					
3514	Commercial/Industrial Eco-Efficiency Measures	N/A (2003 Report)	N/A (2003 Report)	N/A (2003 Report)	N/A
3516	*Household Stormwater Recycling*				
7043	Economic Prosperity	Mixed, Undetermined (2003 Report)	Mixed, Undetermined (2003 Report)	Mixed, Undetermined (2003 Report)	Mixed (L. Superior basin)
7056	Water Withdrawals	Mixed, Unchanging	Mixed, Unchanging (2005 Report)	Mixed, Unchanging	
7057	Energy Consumption	Mixed, Undetermined (2005 Report)	Mixed, Undetermined (2005 Report)	Mixed, Undetermined	Mixed, Deteriorating
7060	Solid Waste Disposal	N/A, Undetermined (2007 Report)	N/A, Undetermined	Mixed (2003 Report)	Mixed
7064	Vehicle Use	Poor, Deteriorating	Poor, Deteriorating		
7065	Wastewater Treatment and Pollution	N/A Progress Report	N/A Progress Report		
CLIMATE CHANGE					
4858	Climate Change: Ice Duration on the Great Lakes	Mixed, Deteriorating	Mixed, Deteriorating	Mixed, Deteriorating (2003 Report)	Mixed, Deteriorating
9003	*Climate Change: Effect on Crop Heat Units*				
PROPOSED INDICATOR					
8164	Biodiversity Conservation Sites	N/A, Undetermined (2007 Report)	N/A, Undetermined		

N/A = Not Assessed; Number in brackets indicates related indicator; Reports are currently unavailable for the indicators in italics.

2.0 Assessing Data Quality

Through both the triennial Conferences and the *State of the Great Lakes* reports (technical report, Highlights report), SOLEC organizers seek to disseminate the highest quality information available to a wide variety of environmental managers, policy officials, scientists and other interested public. The importance of the availability of reliable and useful data is implicit in the SOLEC process.

To ensure that data and information made available to the public by federal agencies adhere to a basic standard of objectivity, utility, and integrity, the U.S. Office of Management and Budget issued a set of Guidelines in 2002 (OMB 2002). Subsequently, other U.S. federal agencies have issued their own guidelines for implementing the OMB policies. According to the Guidelines issued by the U.S. Environmental Protection Agency (U.S. EPA 2002), information must be accurate, reliable, unbiased, useful and uncompromised though corruption or falsification.

Other assessment factors (U.S. EPA 2003) that are typically taken into account when evaluating the quality and relevance of scientific and technical information include:

- **Soundness** - the extent to which the scientific and technical procedures, measures, methods or models employed to generate the information are reasonable for, and consistent with, the intended application
- **Applicability and Utility** - the extent to which the information is relevant for the intended use
- **Clarity and Completeness** - the degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations and analyses employed to generate the information are documented
- **Uncertainty and Variability** - the extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods or models are evaluated and characterized
- **Evaluation and Review** - the extent of independent verification, validation and peer review of the information or of the procedures, measures, methods or models

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

- Data are documented, validated, or quality-assured by a recognized agency or organization.
- Data are traceable to original sources.
- The source of the data is a known, reliable and respected generator of data.
- Geographic coverage and scale of data are appropriate to the Great Lakes basin.
- Data obtained from sources within the United States are comparable with those from Canada.

Additional considerations include:

- Gaps in data availability should be identified if datasets are unavailable for certain geographic regions and/or contain a level of detail insufficient to be useful in the evaluation of a particular indicator.
- Data should be evaluated for feasibility of being incorporated into indicator reports. Attention should be given to budgetary constraints in acquiring data, type and format of data, time required to convert data to usable form, and the collection frequency for particular types of data.

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

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

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

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

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

Sources

Office of Management and Budget. 2002. *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies*, (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.

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

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

3.0 Indicator Category Assessments and Management Challenges

COASTAL ZONES AND AQUATIC HABITATS

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Great Lakes coastal zones are unique and rare in the world of freshwater ecosystems. Special lakeshore communities such as coastal wetlands, islands, alvars, cobble beaches, sand dunes as well as aquatic habitats, however, are being adversely impacted by the artificial alteration of natural water level fluctuations, shoreline hardening, development, and elevated phosphorus concentrations and loadings. New data and new management approaches indicate a potential for reversing the deteriorating conditions identified in some locations.**

The alteration of natural lake level fluctuations significantly impacts nearshore and coastal wetland vegetation. Water levels are regulated in Lake Superior and Lake Ontario and are less variable than in the other Great Lakes. In Lake Ontario, the reduced variation in water levels has resulted in coastal wetlands that are markedly poor in plant species diversity.

The St. Clair, Detroit, and Niagara Rivers have 44 to 70 percent of their shorelines artificially hardened. Of the lakes, Lake Erie has the highest percentage of its shoreline hardened, and Lake Huron and Lake Superior have the lowest. Whether the amount of shoreline hardening can be reduced is uncertain; perhaps there may come a time when shorelines can be restored to a more natural state.

The ecological importance of the Great Lakes special lakeshore communities such as alvars, cobble beaches and sand dunes are increasingly being recognized. More than 90 percent of Great Lakes alvars, open habitats occurring on flat limestone bedrock, have been destroyed or substantially degraded, but conservation efforts now recognize their importance as habitats for rare plants and animals. Cobble beaches, another unique habitat, are decreasing due to shoreline development. Increasingly, human development damages the connectedness and quality of the sand dune system; however progress is being made in protecting and restoring critical dune habitats.

The more than 31,000 Great Lakes islands form the world's largest freshwater island system and their biological diversity is of global significance. Islands are of particular importance for colonial nesting waterbirds, migrating songbirds, unique plants, endangered species, and fish spawning and nursery areas. Islands are vulnerable to impacts from shoreline development, invasive species, recreational use and climate change.

Management Challenges:

- Regulate water levels in a manner that allows for healthy aquatic habitats.
- Protect and restore wetlands, islands, alvars, cobble beaches, sand dunes, and aquatic habitats.
- Implement established binational coastal wetland monitoring programs and protocols.
- Develop indicators for all aquatic habitats: open and nearshore waters, groundwater, rivers and streams, inland lakes and wetlands.

COASTAL ZONES and AQUATIC HABITATS

ID #	Indicator Name	2009 Assessment (Status, Trend) Lake SU	MI	HU	ER	ON
COASTAL ZONES						
Nearshore Aquatic						
4861	Effect of Alteration of Natural Water Level Fluctuations	? (Mixed)	? (Mixed)	? (Mixed)	? (Mixed)	← (Mixed)
8131	Extent of Hardened Shoreline	? (Not Assessed)				
Coastal Wetlands						
4501	Coastal Wetland Invertebrate Community Health	Progress Report				
4502	Coastal Wetland Fish Community Health	Progress Report				
4504	Coastal Wetland Amphibian Communities	? (Not Assessed)	← (Mixed)	← (Mixed)	◆ (Mixed)	← (Mixed)
4506	Contaminants in Snapping Turtle Eggs	? (Not Assessed)	? (Not Assessed)	? (Not Assessed)	? (Mixed)	? (Mixed)
4507	Coastal Wetland Bird Communities	? (Not Assessed)	← (Mixed)	← (Poor)	← (Mixed)	← (Mixed)
4510	Landscape Extent and Composition	? (Not Assessed)				
4861	Effect of Alteration of Natural Water Level Fluctuations	? (Mixed)	? (Mixed)	? (Mixed)	? (Mixed)	← (Mixed)
4862	Coastal Wetland Plant Communities	? (Mixed)	? (Fair)	? (Fair)	← (Fair)	◆ (Poor)
4863	Land Cover Adjacent to Coastal Wetlands	Progress Report				
Terrestrial						
4861	Effect of Alteration of Natural Water Level Fluctuations	? (Mixed)	? (Mixed)	? (Mixed)	? (Mixed)	← (Mixed)
8129	Area, Quality and Protection of Special Lakeshore Communities - Alvars	? (Not Assessed)				
8129	Area, Quality and Protection of Special Lakeshore Communities - Cobble Beaches	? (Not Assessed)				
8129	Area, Quality and Protection of Special Lakeshore Communities - Islands	? (Good)	? (Mixed)	? (Mixed)	? (Mixed)	? (Mixed)
8129	Area, Quality and Protection of Special Lakeshore Communities - Sand Dunes	? (Not Assessed)	← (Good)	? (Not Assessed)	→ (Mixed)	→ (Mixed)
8131	Extent of Hardened Shoreline	? (Not Assessed)				
AQUATIC HABITATS						
Open Lake						
111	Phosphorus Concentrations and Loadings — open lake	◆ (Good)	→ (Good)	◆ (Good)	◆ (Fair/Poor)	→ (Good)
	nearshore	? (Not Assessed)	? (Poor)	? (Poor)	? (Poor)	? (Poor)
118	Toxic Chemical Concentrations in Offshore Waters	? (Fair)	? (Fair)	? (Fair)	? (Mixed)	? (Mixed)
119	Concentrations of Contaminants in Sediment Cores	? (Not Assessed)				
8131	Extent of Hardened Shoreline	? (Not Assessed)				
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 Groundwate Discharge	? (Not Assessed)				
7103	Groundwater Dependent Plant and Animal Communities	? (Not Assessed)				

Status					Trend			
(grey)	(green)	(yellow)	(red)	(tan)	→	◆	←	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.

INVASIVE SPECIES

Overall Assessment

Status: **Poor**
Trend: **Deteriorating**
Rationale: **New non-native species, now totalling 185 aquatic and at least 157 terrestrial species, continue to be discovered in the Great Lakes. Each new non-native species can interact with the ecosystem in unpredictable ways, with at least 10 percent of non-native species considered to be invasive, meaning that they negatively impact ecosystem health. The presence of invasive species can be linked to many current ecosystem challenges including the decline in the lower food web's *Diporeia* populations, fish and waterfowl diseases, and excessive algal growth. Shipping continues to be a major concern for introductions and spread of invasive species. However, the roles of canals, online purchase of aquatic plants, and the aquarium and fish-bait industries are receiving increasing attention.**

Managing the impact of harmful invasive species once they are established is a major challenge. For example, the invasive sea lamprey is an established lethal parasite to large Great Lakes fishes. Decades of control measures have reduced the sea lamprey population by over 90 percent from its peak, but the need for sea lamprey control continues. The success of control efforts are measured against sea lamprey target population ranges agreed to by fishery management agencies, which should result in tolerable fish mortality rates.

The Great Lakes ecosystem has been, and will continue to be, extremely vulnerable to introductions of new invasive species because the region is a significant receptor of global trade and travel. The vulnerability of the ecosystem to invasive species is elevated by factors such as climate change, development and previous introductions.

Management Challenges:

- Develop integrated invasive species prevention and control strategies for the entire basin.
- Establish and enforce regulations to inhibit the introduction and spread of aquatic invasive species.
- Gain a better understanding of the links between vectors and donor regions, the reactivity of the Great Lakes ecosystem, and the biology of potential harmful invaders.

INVASIVE SPECIES

ID #	Indicator Name	2009 Assessment (Status, Direction)				
		Lake				
		SU	MI	HU	ER	ON
Aquatic						
18	Sea Lamprey	➡ (yellow)	⬅ (red)	◆ (yellow)	◆ (red)	◆ (green)
9002	Non-Native Species (Aquatic)	◆ (yellow)	⬅ (red)	⬅ (red)	⬅ (red)	⬅ (red)
Terrestrial						
9002	Non-Native Species (Terrestrial)	? (grey)				

Status					Trend			
(grey)	(green)	(yellow)	(red)	(tan)	➡	◆	⬅	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.

CONTAMINATION

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Improvements in drinking water assessment techniques and beach monitoring, along with continuing declines in concentrations of PCBs in fish and air, are being made and help to protect human health. Incompletely known are global or continental factors that may be limiting the success of air pollution reduction efforts. Continued reduction of pollution sources near beaches and continued study of the impacts of non-native mussels on beach water quality are also needed.**

Colonial waterbirds, such as the herring gull, are fish-eaters and usually considered top-of-the-food web predators. They are excellent bioaccumulators of contaminants and are often among the species with the greatest pollutant levels in an ecosystem. They also breed on all the Great Lakes. Overall, most contaminants in herring gull eggs have declined 90 percent or more since the monitoring began in 1974, but recently, the rate of decline has slowed. More physiological abnormalities in herring gulls still occur at Great Lakes sites than at cleaner reference sites away from the Great Lakes basin.

Since the 1970s, concentrations of historically-regulated contaminants such as polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloroethane (DDT) and mercury have generally declined in most monitored fish species. Concentrations of other regulated and unregulated contaminants such as chlordane and toxaphene vary in selected fish communities, and these concentrations are often lake-specific. Overall, there has been a significant decline in these contaminant concentrations. However, the rate of decline is slowing and, in some cases concentrations are even increasing in certain fish communities.

Excessive inputs of phosphorus to the lakes from detergents, sewage treatment plants, agricultural runoff, and industrial discharges can result in nuisance algae growth. Efforts that began in the 1970s to reduce phosphorus loadings have been largely successful. However, in some locations, phosphorus loads may be increasing again, and an increasing proportion of the phosphorus is a dissolved form that is biologically available to fuel nearshore algal blooms. The status and trends of phosphorus can be quite different in the nearshore waters compared to the offshore waters of each lake.

Substances of emerging concern such as flame retardants, plasticizers, pharmaceuticals and personal care products, and pesticides have been at the forefront of many recent studies because they may pose a risk to fish, wildlife or people. Polybrominated diphenyl ethers (PBDEs, flame retardants incorporated into many products), for example, have recently been added to fish monitoring programs in Canada and the United States. Program results demonstrate that voluntary and regulatory action on the more toxic formulations of PBDEs through the mid-2000s resulted in a prompt decrease of concentrations of these contaminants in Great Lakes fish. Perfluoroctanesulfonate (PFOS), which is a product used in surfactants such as water-repellent coatings and fire-suppressing foams, has been detected in fish throughout the Great Lakes and has demonstrated the capacity for biomagnification in food webs.

Atmospheric deposition of toxic compounds to the Great Lakes will continue into the future. Levels of banned organochlorine pesticides are generally decreasing. Levels of persistent bioaccumulative toxic substances in air tend to be lower over Lake Superior and Lake Huron, but they may be much higher in some urban areas around the lakes.

Management Challenges:

- Eliminate nuisance algae growth through vigilant efforts to control excessive phosphorus loadings to the Great Lakes, guided by a better understanding of the location and relative importance of various sources as well as the role that some invasive species play in the cycling of phosphorus.
- Research human and ecosystem health implications of detected bioaccumulative toxic substances and newly monitored contaminants in the Great Lakes.
- Reduce atmospheric deposition of contaminants to the Great Lakes.
- Remove existing sources of PCBs in the Great Lakes basin.
- Systematically measure toxic chemicals from all vectors to improve source identification and local management actions.

CONTAMINATION

ID #	Indicator Name		2009 Assessment (Status, Trend)				
			Lake				
			SU	MI	HU	ER	ON
Nutrients							
111	Phosphorus Concentrations and Loadings	open lake	Green ◆	Green ➡	Green ◆	Fair/Poor ◆	Green ➡
		nearshore	Grey ?	Red ?	Red ?	Red ?	Red ?
7061	Nutrient Management Plans		Grey ?				
Toxics in Biota							
114	Contaminants in Young-of-the-Year Spottail Shiners		Tan ➡	Grey ?	Tan ➡	Tan ➡	Tan ➡
115	Contaminants in Colonial Nesting Waterbirds		Green ➡	Tan ➡	Tan ➡	Tan ➡	Tan ➡
121	Contaminants in Whole Fish		Yellow ➡	Yellow ➡	Yellow ➡	Yellow ➡	Yellow ➡
124	External Anomaly Prevalence Index for Nearshore Fish		Grey ?	Grey ?	Grey ?	Red ◆	Red ◆
4177	Biologic Markers of Human Exposure to Persistent Chemicals		Grey ?	Grey ?	Grey ?	Grey ?	Grey ?
4201	Contaminants in Sport Fish		Tan ◆	Tan ➡	Tan ➡	Tan ◆	Tan ➡
4506	Contaminants in Snapping Turtle Eggs		Grey ?	Grey ?	Grey ?	Tan ?	Tan ?
8135	Contaminants Affecting Productivity of Bald Eagles		Grey ?				
8147	Population Monitoring and Contaminants Affecting the American Otter		Grey ?				
Toxics in Media							
117	Atmospheric Deposition of Toxic Chemicals	PCBs & others	Grey ?				
		PAHs & mercury	Grey ?				
118	Toxic Chemical Concentrations in Offshore Waters		Yellow ?	Yellow ?	Yellow ?	Tan ?	Tan ?
119	Concentrations of Contaminants in Sediment Cores		Grey ?				
4175	Drinking Water Quality		Grey ?				
4202	Air Quality		Grey ?				
9000	Acid Rain		Grey ?				
Sources and Loadings							
117	Atmospheric Deposition of Toxic Chemicals	PCBs & others	Grey ?				
		PAHs & mercury	Grey ?				
4202	Air Quality		Grey ?				
7065	Wastewater Treatment and Pollution		Progress Report				
9000	Acid Rain		Grey ?				

Status					Trend			
Grey	Green	Yellow	Red	Tan	➡	◆	⬅	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.

HUMAN HEALTH

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Improvements in drinking water assessment techniques and beach monitoring, along with continuing declines in concentrations of PCBs in fish and air, are being made and help to protect human health. Incompletely known are global or continental factors that may be limiting the success of air pollution reduction efforts. Continued reduction of pollution sources near beaches and continued study of the impacts of non-native mussels on beach water quality are also needed.**

A suite of ten health-related parameters are used to assess treated drinking water quality in the Great Lakes region. The parameters include chemical and bacterial contaminants as well as treatment success. According to these parameters, the Great Lakes provide residents with some of the finest drinking water sources found anywhere in the world, and water treatment plants in both Canada and the United States are using successful treatment technologies. However, drinking water treatment facilities generally do not completely eliminate all contaminants.

Based on 2007 data from over 1600 beaches along the U.S. and Canadian coastlines of the Great Lakes, an average of 67 percent were open more than 95 percent of the swimming season. In general, Lake Erie and Lake Ontario have more beach advisories, postings, and closures than Lake Superior, Lake Michigan and Lake Huron due to a greater number of both point and non-point sources of pollution in the lower Great Lakes.

A decrease in the concentration of contaminants in sport fish can be attributed to the elimination of the use of a number of persistent bioaccumulative toxic chemicals in the environment, mainly organochlorine contaminants such as toxaphene. Although declines in PCB concentrations have been observed in lake trout, concentrations still exceed consumption limits so it is important to continue monitoring. Some new persistent bioaccumulative chemicals of concern have been detected in fish and are now being monitored.

Air quality seems to be improving on a regional scale, but localized problem areas still exist. In the United States portion of the Great Lakes basin, concentrations of nitrogen oxides and ground-level ozone are decreasing. These successes are attributed to improvements in urban areas. In the Canadian portion of the basin, concentrations of nitrogen oxides have also decreased as a result of improvements in urban areas and although ozone levels remain a concern, there has been an overall decreasing trend in peak ozone concentrations. This decrease is partly due to weather conditions less conductive for ozone production, and the reductions of nitrogen oxide emissions in Ontario and in the United States.

Management Challenges:

- Protect Great Lakes drinking water sources from potential threats to human health, including many contaminants, pathogenic bacteria, salts in stormwater runoff, and chemicals of emerging concern such as pharmaceuticals and personal care products, endocrine disruptors, antibiotics and antibacterial agents.
- Review and standardize U.S. state guidelines for contaminants in sport fish.
- Monitor chemicals of emerging concern such as PBDEs and PFOS.
- Identify human and ecosystem effects from exposure to multiple contaminants, including endocrine disruptors.
- Improve quantitative measurements for water quality improvements that can be expected as a result of implementing various best management practices.

HUMAN HEALTH

ID #	Indicator Name	2009 Assessment (Status, Trend)				
		Lake				
		SU	MI	HU	ER	ON
4175	Drinking Water Quality	?				
4177	Biological Markers of Human Exposure to Persistent Chemicals	?	?	?	?	?
4200	Beach Advisories, Postings and Closures	US-◆ CA-➡	➡	US-◆ CA-➡	⬅	US-◆ CA-⬅
4201	Contaminants in Sport Fish	◆	➡	➡	◆	➡
4202	Air Quality	?				

Status					Trend			
					➡	◆	⬅	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.

BIOTIC COMMUNITIES

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Overall, the status of biotic communities varies from one lake to another, with Lake Superior generally having a more positive status than the other lakes. Indicators that measure lower food web components generally show more negative status and trends, and most of these can be related back to the impacts of invasive zebra and quagga mussels. Some indicators that focus on higher food web components are more positive and highlight the successes that can be achieved as a result of long-term restoration and protection efforts.**

Bottom-dwelling, or benthic, aquatic organisms are important to, and indicative of, aquatic ecosystem health. The diversity of benthic organisms in Lake Superior, Lake Huron, and Lake Michigan is typical of nutrient-poor, oxygen-rich conditions. In contrast, the community of benthic organisms in Lake Erie is more typical of an aquatic ecosystem with low oxygen, nutrient-rich conditions.

Diporeia is an aquatic invertebrate that is an important food source for preyfish, and its populations have declined drastically in all lakes except Lake Superior. The decline began after the arrival of zebra and quagga mussels, but their continuing downward trend is far more complex. The continuing decline will have serious consequences for the food web, and impacts are being observed in populations of preyfish such as whitefish, bloater and sculpin.

In the lower Great Lakes, over 99 percent of the native freshwater mussel population has been wiped out by the establishment of invasive zebra and quagga mussels. There are a few isolated nearshore communities of native mussels that are still reproducing, with coastal wetlands acting as refugia for native mussels. Recent research on native mussels in the St. Lawrence River shows that after a period of time following an invasion, the numbers of native mussels in open waters may stabilize and natural reproduction may resume.

Preyfish, including bloater and sculpin, are a group of species that eat aquatic invertebrates and are an important food source for trout, salmon and other large predatory fish. Maintaining healthy preyfish populations is essential for supporting lake trout restoration as well as sport and commercial fishing interests. The impacts of the decline of preyfish populations and shift in biotic communities will continue to be an issue of concern for the near future.

Lake Superior is currently the only lake where natural reproduction of lake trout has been re-established and maintained. In Lake Huron, self-sustaining populations occur at a few locations in Georgian Bay in Canada. In the U.S. waters of Lake Huron there are widespread but low levels of natural reproduction. Natural reproduction has been occurring in Lake Michigan and Lake Ontario at very low levels. To improve survival in Lake Erie, a deepwater strain of Lake Superior lake trout is being introduced and is also being considered for Lake Ontario. These fish may be better suited to survive in offshore habitats not colonized by traditional strains.

Most salmon populations are successfully reproducing and are now considered to be naturalized to the Great Lakes ecosystem.

Many self sustaining populations of lake sturgeon still exist in the Great Lakes but at a very small fraction of their estimated historical abundance. Successful river spawning sites remain on each of the Great Lakes, with a total of twenty-seven confirmed locations. Larger than average populations still reside in the North Channel and southern Main Basin of Lake Huron and in the St. Clair / Detroit River connecting waters, including Lake St. Clair. Agencies continue to work together to develop management strategies to strengthen existing populations and reintroduce new ones.

Walleye populations in all the Great Lakes connecting channels have benefited from very good hatches in 2003. This has resulted in good angler catches throughout the region and a commercial walleye harvest in Lake Erie. In the Saginaw Bay portion of Lake Huron, the walleye population is nearing the recovery criteria set by the Michigan Department of Natural Resources. However, there is inconsistency in achieving walleye population and harvest targets due to the highly variable quality of walleye hatches in many of the lakes.

Despite significant historical declines, the Great Lakes bald eagle population is on the rebound. In 2007, the bald eagle was removed from protection under the U.S. Endangered Species Act, although it is still protected by two other pieces of U.S. federal legislation. In Ontario, the Great Lakes bald eagle population is protected by the Endangered Species Act, although the national population does not currently receive federal protection. The governments of Canada and the United States are working together on a binational initiative to identify, prioritize, and improve bald eagle habitat sites.

Management Challenges:

- Enhance native preyfish populations.
- Establish appropriate fish stocking levels in relation to the health of the preyfish population base.
- Improve biomonitoring programs and maintain trend data, including those for bald eagles.
- Protect existing high-quality nearshore areas.
- Plan and implement restoration projects that maximize benefits to all biotic communities, for example by incorporating native mussel refugia into coastal wetland restoration plans.
- Monitor fish communities to understand the relationship between *Diporeia* and zebra and quagga mussels.

BIOTIC COMMUNITIES

ID #	Indicator Name	2009 Assessment (Status, Trend) Lake: SU	MI	HU	ER	ON
Fish						
8	Salmon and Trout	(Fair) →	(Mixed) →	(Fair) →	(Good) →	(Mixed) ◆
9	Walleye	(Fair) ?	(Mixed) ?	(Good) →	(Mixed) ◆	(Fair) ◆
17	Preyfish Populations	(Mixed) →	(Mixed) ←	(Mixed) ←	(Mixed) ←	(Mixed) ←
93	Lake Trout	(Good) →	(Poor) ◆ ←	(Mixed) →	(Mixed) ◆	(Mixed) ←
125	Status of Lake Sturgeon in the Great Lakes	(Mixed) ? →	(Mixed) ? →	(Mixed) ? →	(Mixed) ? →	(Mixed) →
4502	Coastal Wetland Fish Community Health	Progress Report				
Birds						
115	Contaminants in Colonial Nesting Waterbirds	(Good) →	(Mixed) →	(Mixed) →	(Mixed) →	(Mixed) →
4507	Coastal Wetland Bird Communities	(Not Assessed) ?	(Mixed) ←	(Poor) ←	(Mixed) ←	(Mixed) ←
8135	Contaminants Affecting Productivity of Bald Eagles	(Not Assessed) ?				
Mammals						
8147	Population Monitoring and Contaminants Affecting the American Otter	(Not Assessed) ?				
Amphibians						
4504	Coastal Wetland Amphibian Communities	(Not Assessed) ?	(Mixed) ←	(Mixed) ←	(Mixed) ◆	(Mixed) ←
7103	Groundwater Dependent Plant and Animal Communities	(Not Assessed) ?				
Invertebrates						
68	Native Freshwater Mussels	(Not Assessed) ?	(Not Assessed) ?	(Not Assessed) ?	(Poor) ←	(Not Assessed) ?
104	Benthos Diversity and Abundance - Aquatic Oligochaete Communities	(Good) ◆	(Mixed) ◆ ←	(Mixed) ◆	(Mixed) ◆ ←	(Mixed) ◆
116	Zooplankton Populations	(Good) ◆	(Not Assessed) ?	(Not Assessed) ?	(Not Assessed) ?	(Not Assessed) ?
122	*Hexagenia*	(Poor) ?	(Poor) ?	(Poor) ?	West L.E. - Mixed to Improving (Good); SW Central L.E. (Mixed) ←	(Not Assessed) ?
123	Abundance of the Benth Amphipod *Diporeia* spp.	(Good) ◆	(Poor) ←	(Poor) ←	(Poor) ←	(Poor) ←
4501	Coastal Wetland Invertebrate Community Health	Progress Report				
Plants						
109	Phytoplankton Populations	(Not Assessed) ?				
4862	Coastal Wetland Plant Communities	(Fair) ?	(Fair) ?	(Fair) ?	(Fair) ←	(Poor) ◆
8500	Forest Lands - Conservation of Biological Diversity	(Not Assessed) ?				

Status					Trend			
(grey)	(green)	(yellow)	(red)	(tan)	→	◆	←	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined

Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.

RESOURCE UTILIZATION

Overall Assessment

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

Less than 1 percent of the Great Lakes waters are renewed annually through precipitation, run-off and infiltration. The net basin water supply is estimated to be 500 billion litres (132 billion gallons) per day, which is equal to the discharge into the St. Lawrence River.

In 2004, water withdrawn from the Great Lakes basin was at a rate of 164 billion litres (43 billion gallons) per day, with 95 percent being returned and 5 percent lost to consumptive use. Of the total withdrawals, 83 percent was for thermoelectric and industrial users and 14 percent was for public water supply systems. Due to the shutdown of nuclear power facilities and improved water efficiency at thermal power plants, water use in Canada and the United States has decreased since 1980. In the future, increased pressures on water resources are expected to come from population growth and from climate change.

The human population of the Great Lakes basin is approximately 42 million. Parameters such as population size, geography, climate, and trends in housing size and density all affect the amount of energy consumed in the basin. Electricity generation was the largest energy-consuming sector in the Great Lakes basin due to the energy required to convert fossil fuels to electricity.

Population growth and urban sprawl in the basin have led to an increase in the number of vehicles on roads, fuel consumption, and kilometres/miles travelled per vehicle. In the Great Lakes states, fuel consumption for vehicles increased by 15 percent on average from 1994 to 2006, as compared to a 28 percent increase nationally in the United States. In Ontario, sale of motor gasoline increased by approximately 23 percent between 1994 and 2006, on par with the Canadian national average. Kilometres/miles travelled within the same areas increased 19 percent for the United States and 66 percent for Canada.

Management Challenges:
- Research the ecological impact of water withdrawals.
- Manage energy production and conservation to meet current and future demands.
- Meet the challenges of population growth and urban sprawl by improving current and future transportation systems and infrastructures.

RESOURCE UTILIZATION

ID #	Indicator Name	2009 Assessment (Status, Trend)				
		Lake				
		SU	MI	HU	ER	ON
3514	Commercial/Industrial Eco-Efficency Measures	?				
7043	Economic Prosperity	?	?	?	?	?
7056	Water Withdrawls	?				
7057	Energy Consumption	?				
7060	Solid Waste Generation	?				
7064	Vehicle Use	?				
7065	Wastewater Treatment and Pollution	Progress Report				

Status					Trend			
					➡	◆	⬅	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined
Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.								

LAND USE—LAND COVER

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Changes on the landscape, due in part to pressures associated with urban population growth, affect the Great Lakes, especially in the nearshore zone where the land meets the water. Changes in land use and land cover affect how water moves across the landscape, and they alter tributary and nearshore flow regimes. Altered flow regimes affect seasonal timing of water inputs and may result in increased erosion, sediment transport, and reduced water quality in tributaries and nearshore areas of the Great Lakes. These changes may modify nearshore aquatic habitat structure and alter ecological functions.**

For the period 1992 to 2001, approximately 800,000 hectares (2 million acres) or 2.5 percent of the Great Lakes basin experienced a change in land use. These changes were dominated by conversion of forested and agricultural lands to either high or low intensity development, transportation (roads), or upland grasses and brush (early successional vegetation). More than half of these changes are considered to be irreversible and permanent. Conversion rates exceeded predictions based on population growth alone.

While good water quality is generally associated with heavily forested or undisturbed areas, forested buffers near surface water features can also protect soil and water resources, despite land use classes present in the rest of the watershed. Higher percentages of forest coverage in these areas reduce local runoff and related problems, while improving the ecosystem's capacity to store water. In the Great Lakes basin, forests cover 69 percent of the land in riparian zones within 30 metres (100 feet) of surface waters.

As coastal areas are developed, shorelines are armoured to protect property and infrastructure. Large navigation structures, marinas, and launch ramps are constructed to promote commerce and recreational uses. Physical alterations to the land/water interface disrupt natural coastal processes which, over time, can have significant regional impacts on nearshore and coastal margin substrates, habitat, hydraulic connectivity, and nearshore water quality. In Ohio, more than 75 percent of the coastline was armored by 2000, and recent recession-line mapping showed a significant increase in the number of shore protection structures installed between 1990 and 2004.

Lake Michigan and U.S. Lake Erie watersheds have the highest proportion of impervious surfaces. The Lake Superior watershed contains the lowest proportion of impervious surfaces within the United States portion of the Great Lakes basin.

Urban population growth in the Great Lakes basin shows consistent patterns in both the United States and Canada. From 1996 to 2006, the population of Canadian metropolitan areas of the Great Lakes basin grew from over 7 million to over 8 million, an increase of 16.3 percent. From 1990 to 2000, the population of United States metropolitan areas of the Great Lakes basin grew from over 26 million to over 28 million, an increase of 7.6 percent. Sprawl is increasing in rural and urban fringe areas of the Great Lakes basin, placing a strain on infrastructure and consuming habitat in areas that previously tended to have healthier environments than those in urban areas. This trend is expected to continue.

Management Challenges:

- Develop a uniform land use/land cover classification system across the basin.
- Update land use/land cover datasets to improve current information availability for management decisions.
- Manage forest lands in ways that protect the continuity of forest cover to allow for habitat protection and wildlife species mobility, therefore maintaining natural biodiversity.
- Develop and promote Green Cities concepts which will accommodate increasing human population while reducing impacts on the Great Lakes basin.

LAND USE - LAND COVER

ID #	Indicator Name	2009 Assessment (Status, Trend)				
		Lake				
		SU	MI	HU	ER	ON
General						
4863	Land Cover Adjacent to Coastal Wetlands	Progress Report				
7002	Land Cover - Land Conversion	?	?	?	?	?
7054	Ground Surface Hardening	?	?	US -? CA -?	US -? CA -?	?
7101	Groundwater and Land: Use and Intensity	?				
Forest Lands						
8500	Forest Lands - Conservation of Biological Diversity	?				
8501	Forest Lands - Maintenance and Productive Capacity of Forest Ecosystems	?				
8503	Forest Lands - Conservation & Maintenance of Soil & Water Resources	?	?	?	?	?
Agricultural Lands						
7028	Sustainable Agriculture Practices	?				
7061	Nutrient Management Plans	?				
7062	Integrated Pest Management	?				
Urban/Suburban Lands						
7000	Urban Density	?				
7006	Brownfields Redevelopment	?				
7054	Ground Surface Hardening	?	?	US -? CA -?	US -? CA -?	?
Protected Areas						
8129	Area, Quality and Protection of Special Lakeshore Communities - Alvars	?				
8129	Area, Quality and Protection of Special Lakeshore Communities - Cobble Beaches	?				
8129	Area, Quality and Protection of Special Lakeshore Communities - Islands	?	?	?	?	?
8129	Area, Quality and Protection of Special Lakeshore Communities - Sand Dunes	?	←	?	→	→
8164	Biodiversity Conservation Sites	?				

Status					Trend			
					→	◆	←	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined
Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.								

CLIMATE CHANGE

Overall Assessment

Climate in the Great Lakes region is changing. Shorter winters, warmer annual average temperatures, and heavy rain and snow and extreme heat events are occurring more frequently. Air and water temperatures are increasing, lake ice cover is decreasing.

The use of long-term historical Intensity-Duration-Frequency curves to design storm retention ponds and other stormwater facilities is no longer adequate because climate change is dramatically altering precipitation and temperature patterns. These changes are expected to alter lake snow pack density, evaporation rates, and water quality. As a result, jurisdictions in Canada and the United States are studying how to adapt to the anticipated impacts of climate change.

Management Challenge:

- Extend global climate change models to Great Lakes regional and local scales, and where possible link to weather models to assist in planning and designing effective stormwater management facilities.

CLIMATE CHANGE

ID #	Indicator Name	2009 Assessment (Status, Trend)				
		Lake				
		SU	MI	HU	ER	ON
4858	Climate Change: Ice Duration on the Great Lakes	?				

Status					Trend			
(grey)	(green)	(yellow)	(red)	(tan)	➡	◆	⬅	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined
Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend.								

4.0 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.

In the cases where indicator reports were brought forward, there were minor formatting changes made to the reports in the English version only. These formatting changes do not affect the content of the report.

Salmon and Trout

Indicator #8

Overall Assessment

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

Lake-by-Lake Assessment

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

Lake Michigan
Status: Mixed
Trend: Improving
Rationale: The number of salmonines stocked each year in Lake Michigan is declining. One goal for Lake Michigan is to establish self-sustaining lake trout populations. Currently, more salmon are stocked than lake trout. This lake has the highest stocking rates of all the Great Lakes.

Lake Huron
Status: Fair
Trend: Improving
Rationale: The number of salmonines stocked each year in Lake Huron is declining, largely due to increased natural reproduction, especially of Chinook salmon. This lake now has the third highest number of stocked salmonines, suggesting an improved reproduction rate leading toward a greater balance in the ecosystem. There are recent indications of more widespread natural production of juvenile lake trout.

Lake Erie
Status: Good
Trend: Improving
Rationale: Lake Erie relies least on stocking of the Great Lakes. The objective for Lake Erie is to provide sustainable harvests of valued fish including lake trout, rainbow trout, and other salmonids. Fisheries restoration programs in Ontario and New York State have established regulations to conserve the harvest and increase fish populations for the next five years.

Lake Ontario
Status: Mixed
Trend: Unchanging
Rationale: Lake Ontario now has the second largest stocking rate (after Lake Michigan). The number of stocked salmonines has slightly declined in the last couple decades, but stocking numbers have been fairly constant in the last three years. The main objective for Lake Ontario is to have a diversity of naturally produced salmon and trout, with an abundance of rainbow trout and Chinook salmon as the top predator. There is an abundance of rainbow trout and Chinook salmon, but the salmon and trout are not naturally reproducing sufficiently to reduce the high numbers of stocked fish each year.

Purpose
- To assess trends in populations of introduced salmon and trout species
- To infer trends in species diversity in the Great Lakes basin
- To evaluate the resulting impact of introduced salmonines on native fish populations and the preyfish populations that support 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" (Great Lakes Fishery Commission (GLFC) 1997).

Fish Community Objectives (FCOs) for each lake address introduced salmonines such as the Chinook and coho salmon, and the 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:

Term	Definition
Salmonine	Refers to 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.

Lake Ontario (1999)
Establish a diversity of salmon and trout with an abundant population of rainbow trout and Chinook salmon as the top predator supported by a diverse preyfish community with 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 trout should be established as the top predator in the offshore benthic community.

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 and non-salmonid species.

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. Achieve and maintain genetically diverse self-sustaining populations of lake trout that are similar to those found in the lake prior to 1940, with lean lake trout being the dominant form in nearshore waters, siscowet lake trout the dominant form in offshore waters, and humper lake trout a common form in eastern waters and around Isle Royale.

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 large oscillations in salmonine-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 salmonids increased dramatically in the 1960s and 1970s. Based on stocking data obtained from the GLFC, approximately 922 million non-native salmonines were stocked in the Great Lakes basin between 1966 and 2005. This estimate excludes the stocking of the Atlantic salmon native to Lake Ontario. Non-native salmonines salmonids do reproduce in the Great Lakes. For example, many of the Chinook salmon in Lake Huron are wild and not stocked. Since 2002, 74 million non-native salmonines have been stocked in the Great Lakes, but the number of stocked salmonines has decreased 32% from 2002 to 2004.

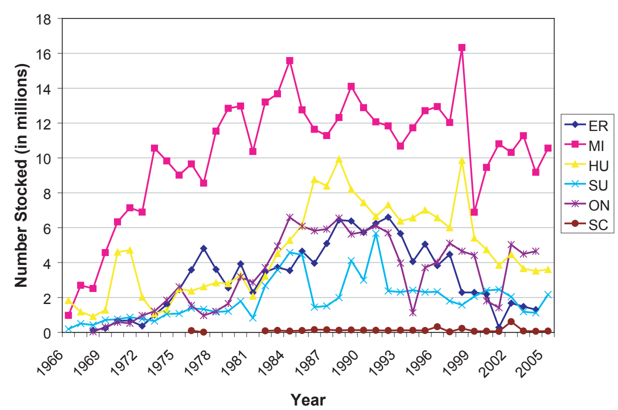

Figure 1. Non-Native salmonine stocking by species in the Great Lakes, 1966-2004 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
ER: Lake Erie, MI: Lake Michigan; HU: Lake Huron; SU: Lake Superior; ON: Lake Ontario; SC: Lake St. Clair.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking).

Of non-native salmonines, Chinook salmon are the most heavily stocked, accounting for about 45% of all non-native salmonine releases (Fig. 1). Rainbow trout are the second highest non-native stocked species, accounting for 25% of all non-native salmonine releases. Chinook salmon, which prey almost exclusively on alewife, are the least expensive of all non-native salmonines to rear, thus making them the backbone of stocking programs in Lake Michigan, Lake Huron and Lake 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 69,000 metric tonnes (76,000 tons) of alewife in Lake Michigan alone are consumed annually by all salmonine predators (Kocik and Jones 1999).

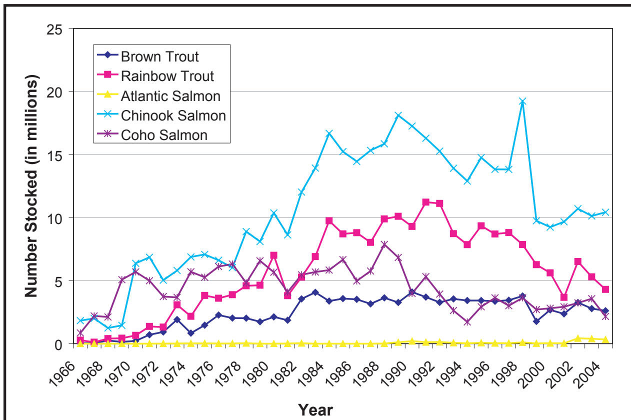

Figure 2. Total number of non-native salmonines stocked in the Great Lakes, 1966-2005 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking).

Data are available for the total number of non-native salmonines stocked in each of the Great Lakes from 1966 to 2005 (Fig. 2). 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 had the lowest rates of stocking, with a maximum greater than 5 million non-native salmonines in 1991. Lake Huron and Lake Erie both display a similar overall downward trend in stocking, especially in recent years, and Lake Ontario has a slightly declining trend in stocking.

The number of stocked salmonines per year in Lake Superior has been nearly steady since 1992. Populations of salmon, rainbow trout and brown trout are being stocked at suitable rates to restore and manage indigenous fish species in Lake Superior. Stocking rates have decreased in recent years suggesting successful reproduction rates and suitable conditions for an improvement towards a balanced ecosystem in the near future.

The number of salmonines stocked each year in Lake Michigan is declining, although the stocking rates remain the highest of all the Great Lakes. One goal for Lake Michigan is to establish self-sustaining lake trout populations. However, naturally reproducing lake trout populations have not yet been re-established. There are currently more salmon than lake trout being stocked.

One goal for Lake Huron is to restore lake trout as the dominant species. Its populations in Lake Huron and Lake Michigan were decimated in the 1950s by over-fishing and predation by the non-native sea lamprey (U.S. Fish and Wildlife Service 2005). The number of lake trout in Lake Huron has increased in the last decade due to the decrease in the numbers of sea lamprey (Madenjian and Desorcie 2004). Since alewife crashed in this lake in 2004, natural reproduction of lake trout has increased in Michigan waters of the lake (Riley *et al.* 2007). This lake now has the third highest number of stocked salmonines, which is an improvement in the balance of the ecosystem since these stocking levels are decreasing.

Lake Erie has low rates of salmonine stocking, similar to those for Lake Superior. The objective for Lake Erie is to provide sustainable harvests of valued fish, including lake trout, rainbow trout, and other salmonids. Fisheries restoration programs in Ontario and New York State have established regulations to conserve the harvest and increase fish populations for the next five years (Lake Erie Lakewide Management Plan 2003). This program is well on its way since there have already been improvements in the fish populations.

Lake Ontario currently has the second highest stocking rate, following Lake Michigan, but the annual rates have been generally declining. 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). The main objective for Lake Ontario is to have a diversity of naturally produced salmon and trout, with an abundance of rainbow trout, and the top predator to be Chinook salmon. Rainbow trout are stocked at the second highest rate in Lake Ontario, following Chinook salmon. Atlantic salmon is also stocked extensively in Lake Ontario. Therefore, part of the goal has been met since the Chinook salmon are readily available as the top predator, and rainbow trout are abundant because of the high stocking levels. However, the objective of having naturally producing salmon and trout has not been met. Salmon and trout are stocked not only to create a balance in the ecosystem, but for a popular recreational activity. Sport fishing is a $3.1 billion annual business, according to a recent industry study (Edgecomb, 2006).

Pressures

The introduction of non-native salmonines into the Great Lakes basin, beginning in the late 1870s, has placed pressures on both the non-native salmonines themselves 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.

Most 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). Predatory salmonines salmonids have the potential to create a situation where prey (alewife) is limiting and ultimately predator survival is reduced (Rand and Stewart 1998). For example, during the 1990s, Chinook salmon in Lake Michigan suffered dramatic declines due to high mortality and high prevalence of bacterial kidney disease 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% 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 based on assessment of forage species and naturally produced salmonines.

Because of its importance as a forage base for the salmonine sport fishery, alewife is no longer viewed as a nuisance by some managers (Kocik and Jones 1999). However, alewife preys on the young of a variety of native fishes, including yellow perch and lake trout, and it competes with native fishes for zooplankton. In addition, the enzyme thiaminase causes early mortality syndrome in salmonines. Alewife contain high levels of thiaminase, possibly threatening lake trout rehabilitation in the lower four lakes and Atlantic salmon restoration in Lake Ontario.

Management Implications

In Lake Michigan, Lake Huron and Lake Ontario, many salmonine species are stocked to maintain an adequate population to suppress non-native prey species (such as 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 because there is a delay before stocked salmon become significant consumers of alewife. Meanwhile, alewife can suffer severe die-offs in particularly harsh 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 Lake Michigan, Lake Huron, and Lake 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.

Comments from the author(s)

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

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments
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Last Updated
State of the Great Lakes 2009

Walleye

Indicator #9

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **A strong 2003 hatch has bolstered walleye abundance in nearly all of the Great Lakes and should keep walleye at moderate levels for the next several years. Variable reproductive success since 2003 will permit walleye population and harvest to increase in select areas. Fisheries harvests of walleye have improved in recent years but remain near or below targets in nearly all areas.**

Lake-by-Lake Assessment

Lake Superior

Status: Fair
Trend: Undetermined
Rationale: Recent recreational harvest estimates showed steady harvest levels in the sport fishery following a peak in 2002 and 2003. Walleye abundance levels in all areas of Lake Superior, with the possible exception of the St. Louis River, are still below historical levels. Rehabilitation efforts of the walleye population in Black Bay, Ontario, are ongoing; however, competing fish community objectives for walleye and sea lamprey (*Petromyzon marinus*) control in the Black Sturgeon River, a Black Bay tributary, will complicate rehabilitation plans.

Lake Michigan

Status: Mixed
Trend: Undetermined
Rationale: Recreational harvest increased to above historical levels in 2007 with the availability of the strong 2003 year class. Tribal fishery yields were not available but were well above average in the four most recent years where data exist (2000-2003). Green Bay stocks appear to be improving, with strong spawning runs in the Fox, Peshtigo, Oconto, and Menominee rivers. Above average reproduction was observed in 2007 in southern Green Bay. Fishery yields in 2007 approached the annual target of 100-200 metric tonnes, but it is difficult to report on the trends and overall achievement of targets without all the components of the harvest.

Lake Huron

Status: Good
Trend: Improving
Rationale: Fishery yields are improving, but are still below the annual harvest target of 700 metric tonnes. Commercial harvest trends continue to decline while recreational harvest trends are improving. This is partly because the greatest gains in harvest have been seen in Saginaw Bay which is closed to commercial fishing. Reproductive success has greatly improved since 2003 in Saginaw Bay and perhaps other parts of the lake, and has been attributed to the decline of the alewife population.

Huron-Erie Corridor (St. Clair River-Lake St. Clair-Detroit River)
Status: Fair
Trend: Unchanging
Rationale: Walleye harvest in this area is down for the early 2000s time period compared to the 1980s. Catch rates for walleye anglers in the corridor remains good. Catch rates have not declined as much as harvest, which may be related to a decline in angler effort to other water areas (i.e., Lake Erie and Saginaw Bay), toward other Huron-Erie Corridor species (i.e., muskie and smallmouth bass), or a change in tactics that are not evaluated (i.e., more evening and night fishing). This fishery has been evaluated on an inconsistent basis, but recent harvest estimates may be as high as 300,000 fish. No continuous fishery data are available to incorporate estimates into our metric ton yield figure, but at an average of about 1 kg/fish, the harvest in this corridor at a few hundred metric tonnes may be as great as that seen in the upper Great Lakes combined. As there exists the potential for sizable harvest, this Huron-Erie Corridor cannot be overlooked in the scale of Great Lakes walleye fisheries and production, and should be included in the indicator description.

Lake Erie
Status: Mixed
Trend: Unchanging
Rationale: The fisheries objective of sustainable harvests lakewide has not been realized since the late 1990s but harvest has been fairly steady for the last several years. Commercial harvest increased substantially in 2005-2007, while recreational fisheries recovered in 2006 and 2007 on the successful recruitment of the 2003 hatch. Harvest by both commercial and recreational fisheries is expected to decrease in 2008 and 2009. "Boom and bust" variable hatches have made long-term attainment of harvest targets difficult, but implementation of a specific harvest policy and a lakewide Walleye Management Plan has assisted managers and stakeholders alike to maintain robust fisheries and adequate fish populations.

Lake Ontario
Status: Fair
Trend: Unchanging
Rationale: After a decade long decline, walleye populations appear to have stabilized. Fishery yields are currently low relative to 1980s and 1990s levels. Recent hatches should keep the population at current or somewhat improved levels of abundance for the next several years.

Purpose
- To show status and trends in walleye populations in various Great Lakes habitats
- To infer changes in walleye health
- 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 and central 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 walleye populations 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, estuaries or bays.

Trends in annual assessments of fishery harvests generally track walleye population recovery in these areas, with peak harvests occurring in the late 1980s to middle 1990s, followed by some declines into the early 2000s, and then increases in most areas after 2002 (Fig. 1). Total yields by lake were highest in Lake Erie (annual average of about 4,500 metric tonnes, recorded from 1975 to 2007 data available), intermediate in Lake Huron (224 metric tonnes), the Huron-Erie Corridor (tonnage unavailable, but up to a half million fish) and Lake Ontario (average of 87 metric tonnes, and lowest in Lake Michigan (average of 16 metric tonnes) and Lake Superior (average of 2 metric tonnes). Declines after the mid-1990s were possibly related to shifts in environmental states (i.e., from mesotrophic, moderately productive conditions to less favorable oligotrophic, low productivity conditions), variable reproductive success, influences from invasive species, and changing fisheries.

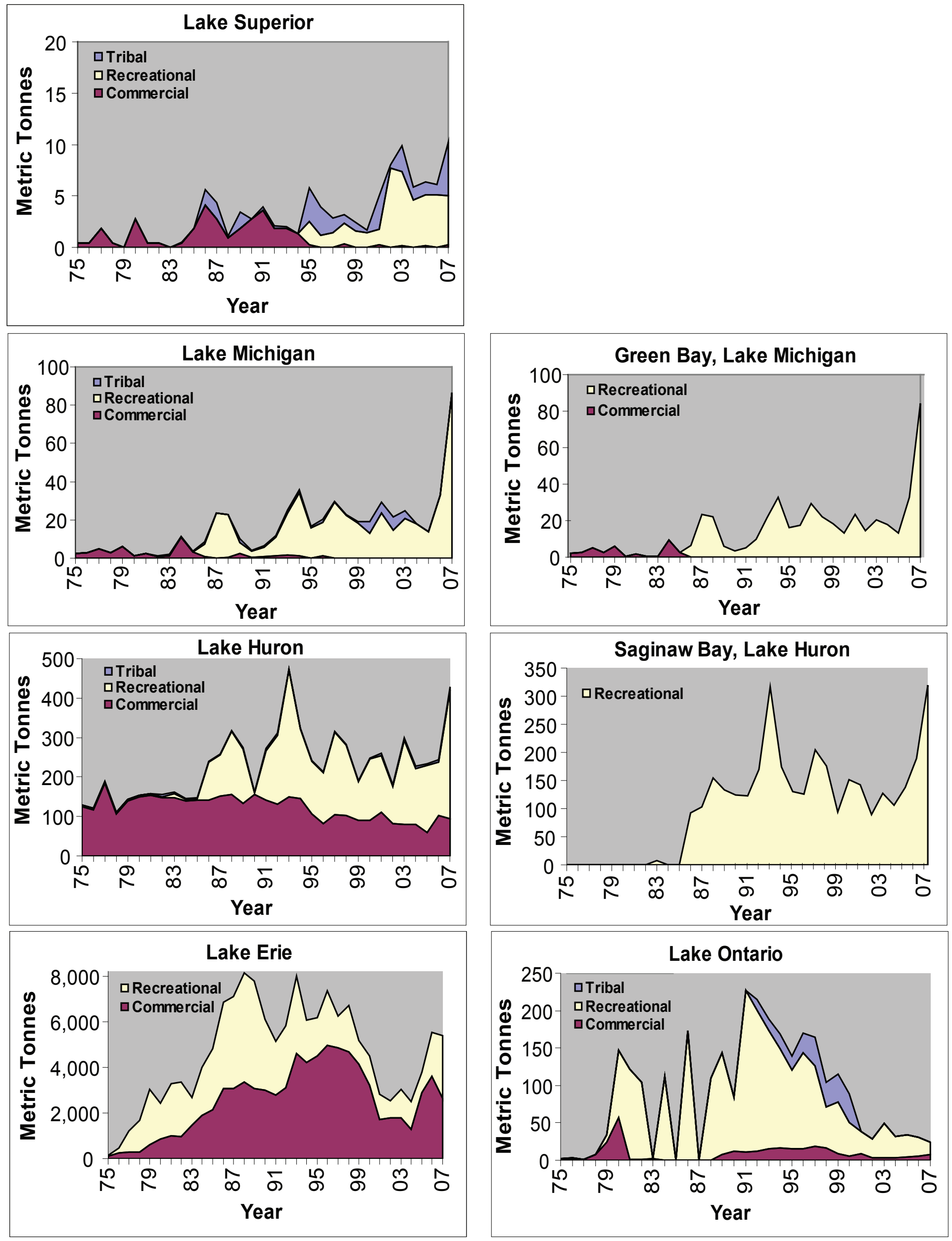

Figure 1. Tribal, recreational and commercial harvest of walleye reported from the Great Lakes, 1975-2007.

Fish Community Goals and Objectives are: Lake Michigan, 100-200 metric tonnes; Lake Huron, 700 metric tonnes; Lake Erie, sustainable harvest in all basins; Lake Ontario, maintain early 1990s populations and expand populations into favorable habitats.

Sources: Chippewa Ottawa Resource Authority, Michigan Department of Natural Resources, Minnesota Department of Natural Resources, New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Ohio Department of Natural Resources, Pennsylvania Fish and Boat Commission, Wisconsin Department of Natural Resources.

Recent improvements in abundance are due to a strong 2003 hatch across the Great Lakes basin, presumably due to ideal regional spring weather conditions. However, in Lake Huron and particularly Saginaw Bay, the production of very strong year classes has continued in four of the last five years beginning in 2003. Recent research has demonstrated that this is a result of the collapse of alewives in Lake Huron. Alewives there are documented to be formidable predators and competitors on newly-hatched walleye fry. In the absence of alewives, it appears that naturally-reproduced walleye fry are experiencing greatly improved survival. Saginaw Bay's walleye population (the largest source of walleye in Lake Huron) is approaching recovery criteria established by the Michigan Department of Natural Resources. This new paradigm may continue as along as alewives remain scarce. It may also give insight into the recovery potential and determining factors limiting walleye recovery in other locations. Lake Ontario has seen similar improvement in walleye recruitment; the 2003-2007 year-classes are on average stronger than the previous five years (1998-2002). Lake Erie hatches have been highly variable; moderate year classes were produced in 1999 (16 million age-2 walleye) and 2001 (12 million age-2 walleye), and 2003 produced a very strong year class at over 50 million age-2 fish, but around those years, very weak year classes were produced in 2000, 2002, 2004 and 2006 (all less than 2 million age-2 walleye). Walleye spawner biomass was constant to increasing during this time period, so adequate egg production was not a controlling factor in the Lake Erie walleye hatch variability.

In general, walleye yields peak or improve dramatically under ideal environmental conditions and fewer or no nuisance species, and decline under less favorable (i.e., non-mesotrophic, less healthy) conditions. Overall, environmental conditions remain improved relative to the 1960s and early 1970s but concerns about food web disruption, pathogens (e.g., botulism, viruses), noxious algae, and poor watershed management practices persist.

Pressures
Natural, self-sustaining walleye populations require adequate spawning and nursery habitats. In the Great Lakes, these habitats exist in tributary streams, and in nearshore reefs, wetlands, and embayments. 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 degradation of nearshore and watershed environments continues to alter the natural hydrologic regime, affecting water quality (i.e., sediment and nutrient 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 invasive species, 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 or changed supply of food or timing of food availability. In many of the Great Lakes food web and environmental changes following zebra and quagga (Dreissenid) mussel invasion likely led to the current lower abundance of walleye. Round goby expansion and predation on Dreissenids has brought some of that energy back into the food web as walleyes have begun to prey on round gobies in many Great Lakes. Recent experience in Lake Huron has elevated the concern over the predatory and competitive effects of the non-native alewife population on walleye. Alterations in the food web can also affect environmental characteristics (like water clarity), which can in turn affect fish behavior and fishery yields. Pathogens, like viral hemorrhagic septicemia and botulism, could also potentially affect walleye populations or their food webs in some areas of the Great Lakes.

Management Implications
To improve the health of Great Lakes walleye populations, managers must enhance walleye reproduction, growth and survival rates. Most walleye populations are dependent on natural reproduction, which is largely driven by uncontrollable environmental events (i.e., winter and spring weather patterns, water clarity, and alewife abundance). However, a lack of suitable spawning and nursery habitat is limiting walleye reproduction in some areas due to human activities and can be remedied through such actions as dam removal, substrate enhancement or improvements to watersheds to reduce siltation and restore natural flow conditions.

Growth rates are dependent on weather (i.e., water temperatures), quality of the prey base, and walleye density - most of which are not directly manageable. Survival rates can be altered through fishery harvest strategies, which are generally conservative across all of the Great Lakes. Continued interactions between land managers and fisheries managers to protect and restore natural habitat conditions in mesotrophic areas of the Great Lakes and in spawning and juvenile walleye habitats are essential for the long term health of walleye populations. Elimination of additional introductions of new non-native invasive species and control of existing non-native nuisance species, where possible, is also critical to future health of the walleye population and other native species.

Fisheries management and public expectations will need to respond to continuing ecosystem changes. Minnesota Department of Natural Resources personnel have developed a Fisheries Management Plan for their waters of Lake Superior. They have identified key areas in the St. Louis River estuary and the Pigeon River system that are important to Lake Superior watershed walleye populations. Most, if not all, agencies have developed or are revising strategic plans for the long-term health of the walleye populations. The Great Lakes Fishery Commission's Lake Erie Committee has drawn up a Walleye Management Plan that delineates desired fishery objectives and a specific harvest policy with thresholds and a sliding fishing harvest rate based on population abundance. Improving long-term data collection and management scenarios will be important to allow managers to understand changes to the walleye populations and fisheries in the Great Lakes.

Comments from the author(s)

Fishery yields are appropriate indicators of walleye health but only in a general sense. Yield assessments are lacking for some fisheries (recreational, commercial, or tribal) in some years for all of the studied areas. Moreover, measurement units are not standardized among fishery types (i.e., commercial fisheries are measured by mass while recreational fisheries are typically measured in numbers of fish), which means additional conversions are necessary which reduce accuracy. Also, "zero" values need to be differentiated from "missing" data in any figures. 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, a 10-year reporting cycle on this indicator is recommended. Many agencies have developed, or are developing, population estimates for many Great Lakes fishes. Walleye population estimates for selected areas (i.e., Lake Erie's western and central basins, 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 switching to them as they become available in all areas is recommended.

Assessing Data Quality

Rather than using the prescribed method (inserting an "x" under the statement that best corresponds with each data characteristic), each parameter is ranked by lake since there were significant differences and variability between the data characteristic assessments across the lakes. Key: LS=Lake Superior, LM=Lake Michigan, LH=Lake Huron, HEC=Huron-Erie Corridor, LE=Lake Erie, and LO=Lake Ontario.

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		LE, LH, LM, LO, HEC	LS			
2. Data are traceable to original sources	LE	LH, LM, LO, HEC	LS			
3. The source of the data is a known, reliable and respected generator of data	LE	LM, LO, HEC	LH, LS			
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		LE, LM, LO	LH, LS, HEC			
5. Data obtained from sources within the U.S. are comparable to those from Canada		LE, LM, HEC	LO, LS	LH		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	LE	LM, LO	LH, LS, HEC			
Clarifying Notes: There is room for improvement. Much of our data is not in yield form (pounds or kilos) and had to be converted. All elements of the harvest are not evaluated on a consistent basis. Knowledge of the population status is based on regular assessment surveys which may be more reliable or are associated with a greater degree of confidence by biologists and managers.						

Acknowledgments

Author:

Kevin Kayle, Ohio Department of Natural Resources (ODNR) (2008)

Sources

Fishery harvest data and management information were obtained from the following sources:

Lake Superior: Ken Cullis, Ontario Ministry of Natural Resources (OMNR), ken.cullis@ontario.ca
Lake Superior/Michigan/Huron: Karen Wright, Chippewa Ottawa Resource Authority, kwright@sault.com
Lake Michigan: David Rowe, Wisconsin Department of Natural Resources, david.rowe@wisconsin.gov
Lake Huron: Lloyd Mohr, OMNR, lloyd.mohr@ontario.ca

Lake Huron: David Fielder, Michigan Department of Natural Resources (MDNR), fielderd@michigan.gov
Huron-Erie Corridor: Megan Belore, OMNR, megan.belore@ontario.ca
Huron-Erie Corridor: Michael Thomas, MDNR, thomasmv@michigan.gov
Lake Erie: Kevin Kayle, ODNR, kevin.kayle@dnr.state.oh.us
Lake Ontario: Jim Hoyle, OMNR, jim.hoyle@ontario.ca
Lake Ontario: Jana Lantry, New York Department of Environmental Conservation, jrlantry@gw.dec.state.ny.us

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

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

Last Updated
State of the Great Lakes 2009

Preyfish Populations

Indicator #17

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**
Rationale: **With the exception of Lake Superior, the Great Lakes fish communities continue to shift away from their natural state. In particular, food webs in the lower lakes are becoming more benthic as a result of the expansion of dreissenid mussels. As a consequence, preyfish populations dependent on pelagic invertebrate production and their salmonid predators have declined and non-native gobies are increasing owing to their ability to thrive in benthic food webs. Mitigation of these changes is not likely due to our inability to manipulate food webs from the bottom-up.**

Lake-by-Lake Assessment

Lake Superior
Status: Mixed
Trend: Improving
Rationale: Abundance of preyfish populations, dominated by native coregonids, continues to fluctuate with a downward trend and is attributed to recruitment variation and predation by recovered lake trout populations. Non-native rainbow smelt remains as a principal component of preyfish assemblage. Round gobies are now present in western Lake Superior and Eurasian ruffe continues to colonize nearshore waters and embayments.

Lake Michigan
Status: Mixed
Trend: Deteriorating
Rationale: Non-native preyfish populations are at historic lows and densities of non-native round goby remain relatively low. However, the decline in *Diporeia* and increasing colonization of dreissenids may signal a shift in food web toward a benthic organization and further community change.

Lake Huron
Status: Mixed
Trend: Deteriorating
Rationale: Non-native preyfish populations are at historic lows. The decline in *Diporeia* and increasing colonization of dreissenids may signal a shift in food web toward a benthic organization and further community change.

Lake Erie
Status: Mixed
Trend: Deteriorating
Rationale: Preyfish (spiny-rayed and softfin fish) populations are increasing, also abundance and distribution of non-native round goby is increasing. Ongoing dreissenid colonization is resulting in further benthification of food web.

Lake Ontario
Status: Mixed
Trend: Deteriorating
Rationale: Non-native preyfish populations are at historic lows while abundance and distribution of non-native round goby is increasing. Ongoing dreissenid colonization is resulting in further benthification of food web. Large areas of deep water are devoid of fish much of the year. A new invasive invertebrate *Hemimysis anomala* was discovered in 2006; its potential effects on the ecosystem are unknown.

Purpose

- To assess the abundance and diversity of preyfish populations
- 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 (FCGOs) for each lake. For example, the Fish Community Objectives (FCOs) 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 stocking programs designed to rehabilitate (or develop new) game fish populations and commercial fisheries. These economically valuable predator species sustain increasingly demanding and highly valued fisheries, and information on their status is crucial. In turn, these apex predators are sustained by preyfish populations. In addition, some preyfishes, such as the bloater and the cisco, which are native species, and the rainbow smelt, which is non-native, are also directly important to the commercial fishing industry. Therefore, it is very important that the current status and estimated carrying capacity of the preyfish populations be fully understood in order to fully address (1) lake trout restoration goals, (2) stocking projections, (3) present levels of salmonid abundance and (4) commercial fishing interests.

The component of the Great Lakes fish communities that we classify as preyfish comprises species – including both pelagic and benthic species – that prey on invertebrates for their entire life history. As adults, preyfish depend on diets of crustacean zooplankton and macroinvertebrates *Diporeia* and *Mysis*. This convention also supports the recognition of particle-size distribution theory and size-dependent ecological processes. Based on size-spectra theory, body size is an indicator of trophic level, and the smaller, short-lived fish that constitute the planktivorous fish assemblage discussed here are a discernable trophic group of the food web. At present, bloaters (*Coregonus hoyi*), cisco (*Coregonus artedi*), rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), and deepwater sculpins (*Myoxocephalus thompsonii*), and to a lesser degree species like lake whitefish (*Coregonus clupeaformis*), ninespine stickleback (*Pungitius pungitius*), round goby (*Apollonia melanostoma*) and slimy sculpin (*Cottus cognatus*) constitute the bulk of the preyfish communities (Fig. 1).

The successful colonization of Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario by non-native dreissenids, notably the zebra mussel (*Dreissena polymorpha*) in the early 1990s and more recently the quagga mussel (*D. bugensis*), has had a significant impact on the trophic structure of those lakes by shunting pelagic planktonic production to mussels, an energetic dead-end in the food chain as few native fishes can eat the mussels. As a result of these profound ongoing changes in trophic structure in four Great Lakes, these ecosystems will continue to change, and likely in unpredictable ways.

In Lake Erie, the preyfish community is unique among the Great Lakes in that it is characterized by relatively high species diversity. The preyfish community comprises primarily gizzard shad (*Dorosoma cepedianum*) and alewife (grouped as clupeids); emerald (*Notropis atherinoides*) and spottail (*N. hudsonius*) shiners, silver chubs (*Hybopsis storeriana*), trout-perch (*Percopsis omiscomaycus*), round gobies and rainbow smelt (grouped as soft-rayed); age-0 yellow perch (*Perca flavescens*) and white perch (*Morone americana*), and white bass (*M. chrysops*) (grouped as spiny-rayed).

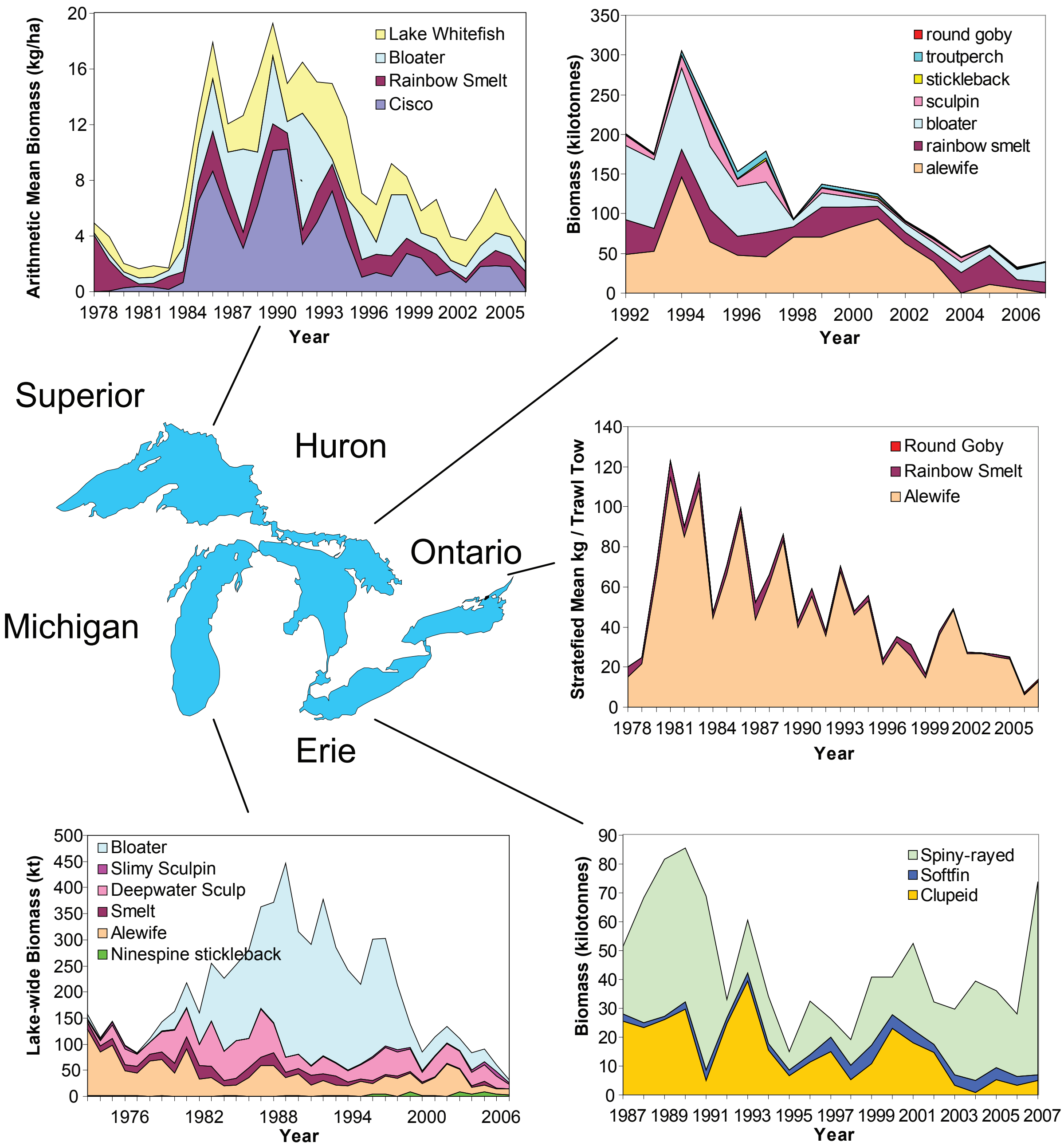

Figure 1. Preyfish trends based on annual bottom trawl surveys. All trawl surveys were performed by USGS - Great Lakes Science Center, except for Lake Erie, which was conducted by the USGS, Ohio Division of Wildlife and the Ontario Ministry of Natural Resources (Lake Erie Forage Task Group), and Lake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

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

State of Preyfish Populations

Lake Superior: Mixed, improving

Since 1994, biomass of Lake Superior preyfish has declined compared to the peak years in 1986, 1990, and 1994, a period when cisco was the dominant preyfish species and wild lake trout populations were starting to recover. Since the early 1980s, dynamics in preyfish biomass have been driven largely by variation in recruitment of age-1 cisco. Strong year classes in 1984, 1988-1990, 1998, and most recently 2003 were largely responsible for peaks in cisco biomass in 1986, 1990-1994, 1999, 2004-2006. Prior to 1984, the non-native rainbow smelt was the dominant preyfish, but fluctuating population levels and recovery of native coregonids after 1984 resulted in reduced smelt biomass and rank among preyfish species. Biomass of bloater and lake whitefish has increased since the early 1980s, and biomass for both species has been less variable than that of cisco. More recently, cisco and bloater abundance has declined sharply since 2006. During 2002 to 2004, rainbow smelt biomass declined to the lowest levels in the 27 years since 1978, though a moderate recovery occurred in 2005-2007. There is strong evidence that declines in cisco, bloater, and rainbow smelt biomass are tied to increased predation by recovered lake trout populations. Other preyfish species, notably sculpins, burbot, and ninespine stickleback have declined in abundance since the recovery of wild lake trout populations in the mid-1980s. Thus, the current state of the Lake Superior preyfish community appears to be largely the result of recruitment variation in prey species, increased predation by recovered wild lake trout stocks, and to a lesser degree, the resumption of human harvest of lake trout, cisco, and lake whitefish.

Lake Huron: Mixed, deteriorating

The Lake Huron fish community changed dramatically from 2003 through 2007, primarily due to a 99% decline in alewife numbers. Loss of alewife appears due to heavy salmonid predation that resulted from increased Chinook salmon abundance as a result of wild reproduction. Alewife population decline was followed immediately by increased reproduction of other fish species; record year classes of walleye and yellow perch were produced in Saginaw Bay, while in the main basin increased reproduction by bloaters (chubs), rainbow smelt, and emerald shiner was observed. From 2004 to 2007, U.S. Geological Survey (USGS) surveys captured over 40 wild juvenile lake trout, more than had been captured in the 30 year history of those surveys. However, despite increased reproduction by prey species, biomass remains low because newly recruited fish are still small. No species has taken the place of alewife, and prey biomass has declined by over 65%. Salmon catch rates by anglers declined, as did average size and condition of those fish. The situation is exacerbated by changes at lower trophic levels. The deepwater amphipod *Diporeia* has declined throughout Lake Huron's main basin, and the zooplankton community has grown so sparse that it resembles the assemblage found in Lake Superior. The reasons underlying these changes are not known, but the most widely held hypothesis is that zebra and quagga mussels are shunting energy into pathways that are no longer available to fish.

Lake Michigan: Mixed, deteriorating

Bloater abundance in Lake Michigan fluctuated greatly from 1973 to 2007, as the population showed a strong recovery during the 1980s but rapidly declined during the late 1990s. Bloater populations may have a cyclic pattern with a period of about 30 years. The substantial decline in alewife abundance during the 1970s and early 1980s has been attributed to increased predation by salmon and trout. The Lake Michigan deepwater sculpin population exhibited a strong recovery during the 1970s and early 1980s, and this recovery has been attributed to the decline in alewife abundance. Alewives have been suspected of interfering with reproduction of deepwater sculpins by feeding upon deepwater sculpin fry. Slimy sculpin abundance appeared to be primarily regulated by predation from juvenile lake trout as it is a favored prey of juvenile lake trout. Temporal trends in abundance of rainbow smelt were difficult to interpret. Yellow perch year-class strength in 2005 was the highest on record dating back to 1973. Thus, early signs of a recovery by the yellow perch population in the main basin of Lake Michigan were evident. The first catch of round gobies in the annual lakewide survey occurred in 2003, and round goby abundance in the main basin of the lake has remained low through 2007. Total preyfish abundance in Lake Michigan during 2007 was at a historic low. Although this low abundance has been tied to the dreissenid mussel invasions, other explanations (including predation by piscivores, movement to deeper water, and characteristics intrinsic to certain preyfish populations) may to be more plausible.

Lake Erie: Mixed, deteriorating

The preyfish community in all three basins of Lake Erie has shown a declining trend. In the eastern basin, rainbow smelt (part of the soft-rayed group) have shown declines in abundance over the past two decades. The trend may be reversing as increases in smelt abundance have occurred over the past two years. The declines have been attributed to lack of recruitment associated with expanding dreissenid colonization and reductions in productivity. The western and central basins also have shown declines in preyfish abundance associated with declines in abundance of age-0 white perch and rainbow smelt, although slight increases for white perch and rainbow smelt have been reported in 2006-2007. The clupeid component of the preyfish community is at the lowest level observed since 1998 and well below the mean biomass for 1987 to 2007. The biomass estimates for western Lake Erie were based on data from bottom trawl catches, depth strata extrapolations (less than and greater than 6 m (20 ft)), and trawl net measurements using acoustic mensuration gear.

Lake Ontario: Mixed, deteriorating
The non-native alewife dominates the preyfish community, but their populations remain at levels well below that of the early 1980s. The rainbow smelt population continues to decrease and has an abbreviated age and size structure suggestive of heavy predation pressure. Abundance of the non-native round goby is increasing and round goby biomass now exceeds that of rainbow smelt. Round goby have the potential to cause a decrease in native, bottom-dwelling preyfish populations such as slimy and deepwater sculpins and trout-perch. Deepwater sculpin populations were thought to be extirpated from the Lake until sporadic catches began to occur during 1996-2004. During 2005-2007, catches of deepwater sculpin increased and juveniles dominated the catches, suggesting a potential population recovery. Deepwater ciscoes, however, have not been reported in the lake since 1983 and the large area of the lake they once occupied is largely devoid of fish for much of the year. A new invasive invertebrate *Hemimysis anomala*, a littoral mysid from the Ponto-Caspian region, was discovered in 2006. Its presence has been confirmed at several locations on both the north and south shores; the risk of foodweb disruption by this species is considered high but little is known of its ecology in the Great Lakes basin.

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

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

Comments from the author(s)
It has been proposed that in order to restore an ecologically balanced fish community, a diversity of prey species at population levels matched to primary production and predator demands must be maintained. However, the current mix of native and naturalized prey and predator species, and the contributions of artificially propagated predator species into the system, confound any sense of balance in lakes other than Lake 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 preyfish in the Great Lakes. Though not an assessment panacea, hydro-acoustics have provided additional insights and have demonstrated utility in yielding more accurate estimates of preyfish biomass.

Long-term preyfish assessment data for Lake Superior is presently restricted to the nearshore waters (15-80 m depth (49-262 feet)) which constitute only ~16% of the Lake surface area. Offshore waters (>80 m depth (262 feet)) constitute ~77% of the Lake surface area and remain poorly studied. Surveys of offshore waters conducted during 2001-2007 reveal a preyfish assemblage dominated by adult cisco, kiyi (*C. kiyi*) and deepwater sculpin (*Myoxocephalus thompsoni*) and the dominant predator is siscowet lake trout. Given the large area of offshore habitat in Lake Superior, consideration of trends in the offshore fish assemblage need to be addressed in assessing the state of the lake-wide fish community. A new Lake Superior assessment program is currently under development and will incorporate sampling in both near- and offshore waters.

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

With the continuous nature of changes that seems to characterize the preyfish populations, and the lower trophic levels on which they depend, the appropriate frequency to review this indicator is on a 3-year basis.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin				X		
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Sea Lamprey

Indicator #18

Overall Assessment

Status: **Fair**
Trend: **Mixed**
Rationale: **Sea lamprey abundances are above target ranges in all lakes except Lake Ontario.**

Lake-by-Lake Assessment

Lake Superior
Status: Fair
Trend: Improving
Rationale: Sea lamprey abundance is above the target range, but has been holding relatively steady since 1999. Sea lamprey abundance has declined beginning in 2005.

Lake Michigan
Status: Poor
Trend: Deteriorating
Rationale: Sea lamprey abundance is above the target range and has been increasing since 2000 with sharp increases each year since 2005.

Lake Huron
Status: Fair
Trend: Unchanging
Rationale: Sea lamprey abundance is above the target range, but has been holding steady.

Lake Erie
Status: Poor
Trend: Unchanging
Rationale: Sea lamprey abundance is above the target range and has been holding steady at pre-control levels since 2005.

Lake Ontario
Status: Good
Trend: Unchanging
Rationale: Sea lamprey abundance is in the target range after three years above the target range. Sea lamprey abundance has been relatively low or in the target range since the mid-1980s.

Purpose

- To estimate adult sea lamprey abundance as an indicator of the status of this invasive species
- To infer the damage caused by sea lamprey to the aquatic ecosystems of the Great Lakes

Ecosystem Objective

This indicator relates to *A Joint Strategic Plan for the Management of Great Lakes Fisheries*: "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 ecosystem." In addition, this indicator supports Annex 2 of the GLWQA.

The 1955 *Convention on 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 *A Joint Strategic Plan for the Management of Great Lakes Fisheries*, all fishery management agencies established fish community objectives for each of the lakes. Fish community objectives call for suppressing sea lamprey populations to levels that cause only insignificant mortality on fish 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 upon target abundance ranges for sea lampreys that will allow achievement of fish community objectives in each lake (Table 1). Targets were derived from estimates of adult sea lamprey abundance and from sea lamprey wounding rates on lake trout (lake trout wounding rates). Suppressing sea lampreys to abundances within the target ranges should 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. Sea lamprey abundance targets and ranges.
Source: Great Lakes Fishery Commission.

State of the Ecosystem

Background

The sea lamprey is a non-native species and a lethal parasite of the larger fishes in the Great Lakes (Bergstedt and Schneider 1988, Kitchell 1990), and has caused ecological and economic tragedy in terms of their impact on the Great Lakes fish communities (Smith and Tibbles 1980). The first complete round of stream treatments with the lampricide TFM (as early as 1960 in Lake Superior) successfully suppressed sea lamprey populations to less than 10% of pre-control abundance in all of the Great Lakes. Never-the-less, the sea lamprey continues to be a significant source of mortality for larger fish (Bergstedt and Schneider 1988, Kitchell 1990) and the need for sea lamprey control continues.

Sea lamprey abundance relative to target ranges in each of the lakes is the primary performance indicator of the sea lamprey control program. Lake-wide sea lamprey abundance estimates are calculated by summing the population estimates generated using mark/recapture, trap catch data extrapolation, and the spawner-discharge model (Mullett *et al.* 2003) methods from streams in a given basin. During 2004, each of the lake committees established explicit target ranges for sea lamprey abundance to support the achievement of fish community objectives. These target ranges represent sea lamprey abundance during years when sea lamprey wounding rates on lake trout were tolerable, that is, affecting fewer than 5% annual mortality, and are estimated from historical sea lamprey abundance estimates and available lake trout wounding data from comparable assessment surveys. Abundance estimates and target ranges for each lake are updated during the early fall of each year.

Status of Sea Lamprey

Annual lake-wide sea lamprey abundance estimates with 95% confidence intervals and the target range for each lake are presented in Figure 1. Annual lake trout wounding rate estimates and targets for each lake are presented in Figure 2.

Lake Superior

During the past 20+ years, sea lamprey abundance has fluctuated, but remained at a level less than 10% of peak abundance (Heinrich *et al.* 2003). Sea lamprey abundance was within the target range during the late 1980s and mid-1990s and reached the lowest level of the time series during 1994. Sea lamprey abundance trended upward from the lowest level until 2001, but has been trending downward since then. Sea lamprey abundance has been above the target range since 1999.

Above target sea lamprey abundance is a threat to the fishery of Lake Superior. Wounding rates on fish have also increased and have not shown the same pattern of decrease seen recently in the sea lamprey abundance estimate. The lake trout wounding rate is above target and increasing, and appears to be most dramatic in the western portion of the lake, but has recently declined in Minnesota waters. Estimates in Michigan waters indicate that sea lamprey-induced mortality on lake trout exceeds fishery-induced mortality, but fishery-induced mortality is low in Michigan waters. Fishery objectives for lake trout continue to be met, but lake trout populations are still threatened by sea lamprey as indicated by the above target abundance and lake trout wounding rate.

In response to the above target sea lamprey abundance and lake trout wounding rate, lampricide treatments were increased beginning in 2001. The effects of the increased treatment efforts may have contributed to the recent downward trend in sea lamprey abundance and this trend is expected to continue. Increased treatment effort will continue and the effects will be observed in future sea lamprey abundance and lake trout wounding rate estimates.

Lake Michigan

Sea lamprey abundance is at about 10% of peak levels, but has been trending upward since 1980 (Lavis *et al.* 2003) and has shown sharp increases during 2004, 2006, and 2007. A sharp decrease was observed during 2005. Sea lamprey abundance was in or below the target range until 2000 and has been above the target range since.

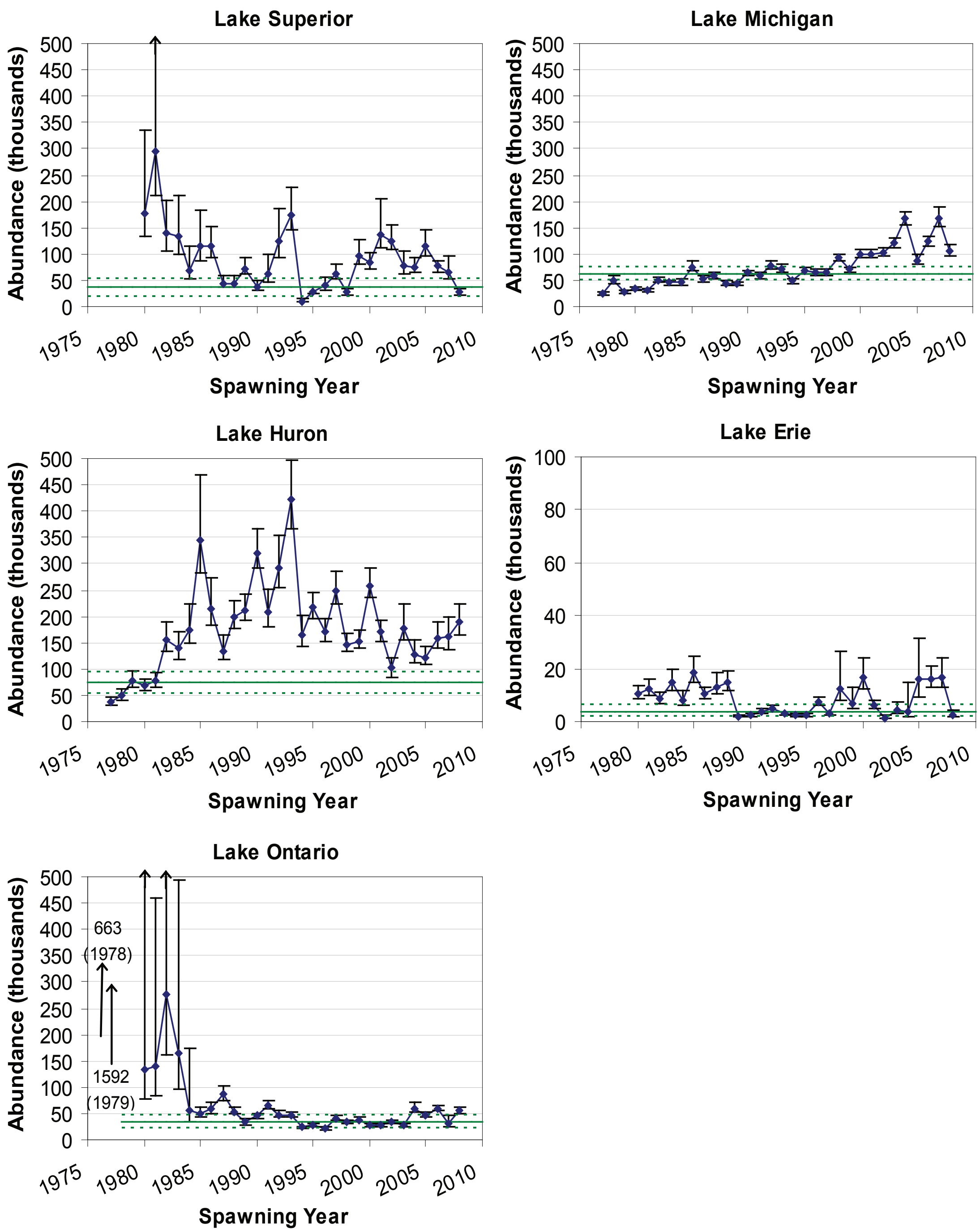

Figure 1. Yearly lake-wide adult sea lamprey abundance estimates with 95% confidence intervals (blue diamonds) presented with the target abundance and range (green horizontal solid and dashed lines) for each lake.
*Note: the scale for Lake Erie is 1/5 that of the lakes.
Source: Great Lakes Fishery Commission.

Above target and increasing sea lamprey abundance is a threat to the fishery of Lake Michigan. The lake trout wounding rate has also shown the same upward trend and is above target, but declining abundance of larger lake trout may be contributing. Increased sea lamprey-induced mortality on lake trout in the northern waters has set lake trout restoration efforts back by a decade. Furthermore, increased mortality is affecting the quota for the commercial fishery to the extent that components of the lake trout management regimen in the consent decree between the tribes, the state, and the federal government are currently suspended. Achievement of lake trout rehabilitation and other fishery objectives will continue to be hampered if sea lamprey abundance and wounding rates on fish remain high and above targets.

Increases in the sea lamprey abundance and lake trout wounding rate during the 1990s were attributed to the St. Marys River. In response, an integrated management approach using lampricides, sterile-male releases, and trapping was initiated in the St. Marys River (Schleen *et al.* 2003) and has reduced the reproductive potential of sea lampreys in the river by about 90%. The continuing upward trend in sea lamprey abundance during the late 1990s and early 2000s indicated there were other significant sources of sea lampreys. Lampricide treatments on Lake Michigan increased during 2001 and included the treatment of newly discovered populations in lentic areas and the Manistique River, a large system where the deterioration of a dam near the river mouth allowed sea lampreys access to hundreds of kilometers of habitat. The 2003 sea lamprey abundance and lake trout wounding rate estimates did not show any decreases as a result of the increased treatments during 2001, however, the sharp decrease in sea lamprey abundance observed during 2005 was most likely associated with the 2003 treatment of the

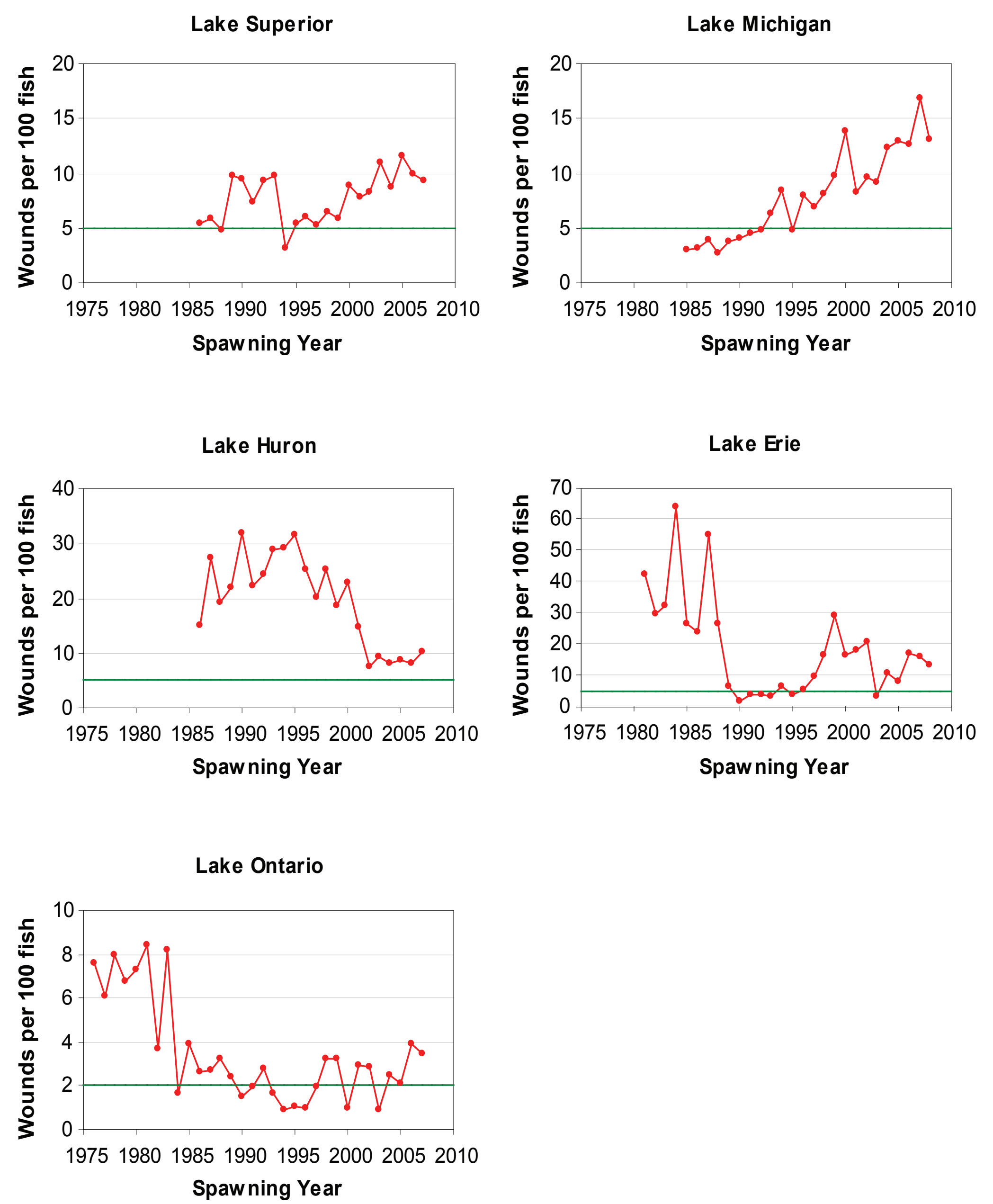

Figure 2. Yearly lake trout wounding rate estimates (red circles) presented with the wounding rate target (green horizontal line) for each lake.
*Note: Lake Ontario reports A1 wounds only (notice different scale); all other lakes report A1-3 wounds.
Source: Great Lakes Fishery Commission.

Manistique River. Increased treatment efforts during recent years, including additional treatments of the Manistique River, have not produced decreases in sea lamprey abundance or the lake trout wounding rate. Other potential sources of sea lampreys are being assessed and increased treatment efforts will continue with the effects to be observed in future sea lamprey abundance and lake trout wounding rate estimates.

Lake Huron
During the past 20+ years, sea lamprey abundance has fluctuated, but remained at a level less than 10% of peak abundance (Morse *et al.* 2003). During the early 1980s, sea lamprey abundance increased from the target range, particularly in the northern portion of the lake, peaking during 1993. Sea lamprey abundance is currently above the target range and has been since 1981.

Above target sea lamprey abundance is a threat to the fishery of Lake Huron. Through the 1990s, there were more sea lampreys in Lake Huron than all the other lakes combined and fishery objectives were not being achieved. Sea lamprey-induced mortality was so severe that during 1995 lake trout restoration efforts were suspended in the northern portion of the lake. There has been a significant reduction in the lake trout wounding rate since the implementation of the integrated management approach on the St. Marys River (lampricide treatment, sterile-male release, and trapping; Schleen *et al.* 2003), which reduced the reproductive potential of sea lampreys in the river by about 90%. Although the lake trout wounding rate is still above target it remains at a low level, lake trout restoration efforts have been continued, and populations are increasing and showing signs of natural reproduction. Never-the-less, lake trout restoration efforts will continue to be hampered if sea lamprey abundance and the lake trout wounding rate remain above targets.

During the 1990s, the St. Marys River was identified as the major source of sea lampreys in Lake Huron, but the size of the river prohibited traditional treatment with the lampricide TFM. In the integrated management approach (lampricide treatment, sterile-male release, and trapping; Schleen *et al.* 2003), a new formulation of a bottom-release lampricide was used in place of TFM with the first full round of treatments happening during 1999. As predicted, the integrated management approach significantly lowered sea lamprey abundance and the lake trout wounding rate. Never-the-less, sea lamprey abundance has been considerably variable since 2001 (the year in which the effects of the 1999 integrated management approach were first observed). Lampricide spot treatments on the St. Marys River have continued in areas with high densities of larvae and treatment efforts have been increased in other areas around the lake during recent years. The effects of additional treatment efforts will be observed during future sea lamprey abundance and lake trout wounding rate estimates.

Lake Erie
Following the completion of the first full round of stream treatments in 1987, sea lamprey abundance plummeted (Sullivan *et al.* 2003) and remained in the target range during 1989 to 1997. Sea lamprey abundance increased briefly during 1998 to 2000, but returned to within the target range during 2001 to 2004. Sea lamprey abundance has been above the target range and has returned to pre-control levels since 2005.

Above target and high sea lamprey abundance is a threat to the fishery of Lake Erie. After the initial stream treatments, the lake trout wounding rate declined and lake trout survival increased to a level sufficient to meet the rehabilitation objectives in the eastern basin. During 1997 to 2002, the lake trout wounding rate increased to and remained at a level that threatened lake trout restoration. The lake trout wounding rate fell below the target during 2003, but has trended upward since and is currently above target. Reductions in lake trout stocking since 1996 may be affecting lake trout abundance, and hence, the lake trout wounding rate. Wounding rates on other fish species have also been increasing. Achievement of lake trout rehabilitation and other fishery objectives will continue to be hampered if sea lamprey abundance and wounding rates on fish remain high and above targets.

The initial stream treatments conducted during 1987 reduced sea lamprey abundance and the lake trout wounding rate to targets. In response to recent (since 2005) increases in sea lamprey abundance to high levels, and above target and increasing lake trout wounding rates, treatment efforts were increased during 2006. Additionally, an aggressive and experimental whole-lake treatment strategy in which all sea lamprey-producing streams are treated in back-to-back years commenced during 2008. The effects of the increased treatment effort and whole-lake treatment experiment will be observed in sea lamprey abundance and lake trout wounding rate estimates during 2008 and beyond.

Lake Ontario
Sea lamprey abundance was greatly reduced following the completion of important lampricide treatments during the 1980s and steadily declined from the mid 1980s to 2003 (Larson *et al.* 2003). Sea lamprey abundance was still relatively low during 2004 to 2006, but was above the target range. Sea lamprey abundance returned to within the target range during 2007 and has been in or near the target range since the mid-1980s.

Although sea lamprey abundance is within the target range, the lake trout wounding rate has not decreased and has been holding steady around the target since the mid-1980s. The lake trout wounding rate has been above target since 2004 and has been high in waters off the mouth of the Niagara River. Changing strain composition of lake trout and reduced abundance of larger fish may be affecting lake trout wounding rates. Achievement of lake trout rehabilitation and other fishery objectives will continue to be hampered if the lake trout wounding rate remains above target or if sea lamprey abundance increases.

The treatment of important streams during the 1980s, including the Black and Oswego systems, precipitated a significant decline in sea lamprey abundance. Subsequent lampricide treatments caused a steady decline in sea lamprey abundance, which has been in or near the target range since the mid-1980s. Lampricide treatments are continuing and sea lamprey abundance and the lake trout wounding rate are expected to remain close to targets during the future.

Pressures
Sea lamprey control in the Great Lakes has successfully reduced sea lamprey abundance from peak levels by about 90%. Sea lampreys, however, still remain a significant source of mortality on the larger fishes of the Great Lakes and a road block to achieving critical fishery objectives. Increasing sea lamprey 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 invasive species. In addition, the potential for sea lamprey to colonize new locations is increased with improved water quality and removal of dams. For example, the failure of the Manistique River dam to block sea lampreys, and the subsequent sea lamprey production from this river, has contributed to the increase in sea lamprey abundance in Lake Michigan. Continuing the search for new or unidentified sources of sea lampreys is critical for sea lamprey control. Any new or unidentified sources of sea lampreys will require some form of control to help attain abundances within the target range in each lake.

As fish communities recover from the effects of sea lamprey predation, there is evidence that sea lamprey populations will benefit from the increase in prey availability. Facilitated through what are called compensatory mechanisms, more sea lampreys may survive due to the increase in prey availability, thus precipitating an increase in reproductive potential and recruitment (i.e. more sea lampreys may be available to prey on fish). To combat potential compensatory responses, significant additional control efforts, like the integrated management approach on the St. Marys River, the experimental whole-lake treatment strategy on Lake Erie, and the implementation or development of alternative sea lamprey control strategies (e.g. barriers, pheromones, genetic controls, etc.) will be necessary to further suppress sea lamprey abundances to target ranges.

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 abundances to increase.

Management Implications
The GLFC has increased stream treatments and lampricide applications in response to increasing sea lamprey abundance estimates during recent years (see status of sea lampreys for each lake above for details). The GLFC has targeted these additional treatments to reduce sea lamprey abundance and lake trout wounding rate to 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.

Comments from the author(s)
Increases in lampricide treatments are predicted to reduce sea lamprey abundances to target ranges. The effects of increased treatments will be observed in this indicator two years after they occur. Discrepancies among abundance estimates of different

life-history stages need to be resolved. Efforts to identify all sources of sea lampreys also need to continue. In addition, research to better understand sea lamprey/prey interactions, the population dynamics of sea lamprey that survive treatment, and refinement of and research into alternative control methods are all keys to maintaining sea lamprey abundances in target ranges.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Native Freshwater Mussels

Indicator #68

Overall Assessment

Status: **Not Assessed**
Trend: **Not Assessed**
Rationale: **With the exception of Lake Erie, only limited data on native unionid populations are available.**

Lake-by-Lake Assessment

Lake Superior

Status: Not Assessed
Trend: Undetermined
Rationale: Only limited data are available for Lake Superior unionid fauna. Some limited surveys have been performed in western nearshore waters as well as some inland rivers, but no widespread unionid population assessments are available for open lake waters (Graf 1997, Graf and Underhill 1997, Nichols *et al*. 2000). Lake Superior has not been well colonized by dreissenid mussels, so unionid population declines related to these invasive species would be limited to a few bays.

Lake Michigan

Status: Not Assessed
Trend: Undetermined
Rationale: Only limited data are available for Lake Michigan unionids. Many inland rivers have been surveyed, but data on open lake populations are rare. Recent sampling has documented declines in other groups of benthic fauna due to dreissenid expansion (Nalepa et.al. 1997). Given the changes in other benthic fauna, and other signs of increasing dreissenid numbers, we hypothesize that unionid population densities in the open lake waters have severely declined over the last decade as they have in Lake Erie.

Lake Huron

Status: Not Assessed
Trend: Undetermined
Rationale: Some unionid population trend data are available for Saginaw Bay, which show a rapid decline of unionids right after the zebra mussel invasion. No concerted sampling of unionids in the open waters of the lake has been performed. Recent benthic sampling has documented changes in non-unionid benthic fauna due to dreissenid expansion (Nalepa *et al*. 1998). We hypothesize that unionid populations are declining as they have in Lake Erie due to the declines in other benthic species and the ever-increasing dreissenid numbers.

Lake Erie

Status: Poor
Trend: Deteriorating
Rationale: Open water surveys show rapid decline of unionids in many parts of the lake due to interactions with dreissenids (Schloesser *et al*. 1997). Unionid populations do survive in some inland rivers.

Lake Ontario

Status: Not Assessed

Trend: Undetermined

Rationale: There are very few studies examining unionid population status in open water, though there are surveys of inland rivers in existence. There are general benthic surveys of open waters that show similar changes in other benthic fauna as dreissenid numbers increase. We hypothesize that the unionid population follows the same pattern of decline, with isolated remnant populations as seen in some of the other lakes.

Purpose

- To assess the location and status of freshwater native mussel (unionid) populations and their habitats throughout the Great Lakes system, with emphasis on endangered and threatened species
- 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 native Great Lakes mussels

Ecosystem Objective

The objective is the restoration of the richness, distribution, and abundance of native mussels throughout the Great Lakes, which would thereby reflect the general health of the basin ecosystems. The long-term goal is for native 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

The richness, distribution, and abundance of mussels reflect the general health of the aquatic ecosystems. Freshwater native 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, nutrient cycling, substrate stability, and water quality. 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—loss of mussels may indicate loss of fish hosts.

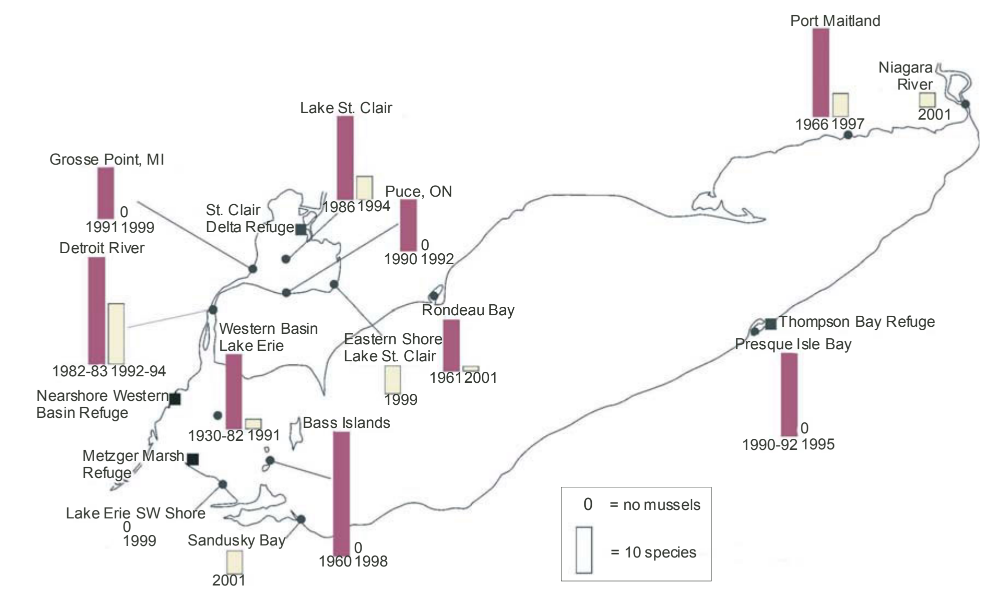

Figure 1. Numbers of freshwater mussel species found before and after the zebra mussel invasion at 13 sites in Lake Erie, Lake St. Clair, and the Niagara and Detroit Rivers (no "before" data available for 4 sites), and the locations of the four known refuge sites (Thompson Bay, Metzger Marsh, Nearshore Western Basin, and St. Clair Delta).
Source: Metcalfe-Smith *et al.* (2002).

Status of freshwater mussels

The abundance and number of species of freshwater mussels have severely declined across North America, including 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 a number of human-mediated factors such as commercial exploitation of the shells, water quality degradation (e.g. pollution, siltation), habitat destruction (e.g. dams, dredging, and channelization) riparian and wetland alterations, changes in the distribution and/or abundance of host fishes, and recently competition with non-native species. In the Great Lakes, the spread and population increase of invasive non-native zebra mussels (*Dreissena polymorpha*) and, to a lesser extent, quagga mussels (*D. bugensis*) have caused a severe decline in the remaining unionid populations in the open waters of lakes Erie, Huron, Michigan, and Ontario, along with any infested inland waters. Zebra and quagga mussels (dreissenids) attach to the native 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.

In the open waters of the lower Great Lakes, such as Lake St. Clair and Lake Erie, over 99% of the native mussels of all species were lost 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 between 1988 and 1990 and from Lake St. Clair between 1988 and 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 (Fig. 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 to 95%.

It was feared that unionid mussels would be completely extirpated from Great Lakes waters. However, remnant native mussel communities have been found in several nearshore areas (Fig. 1). These remnant unionid populations, found in isolated habitats such as river mouths and lake-connected wetlands, are at severe risk.

All of the refuge sites discovered to date have two characteristics in common: they are very shallow (less than 1 to 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. Increased predation by nearshore fish have reduced attached dreissenid at some sites. 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.

Uniodid populations in these types of refugia are still at risk of extirpation due to their isolation and fragmentation. Reproduction is occurring at some of these sites, but not all. While multiple species are found in these sites, viable population numbers of some rarer species may not be present, leading to concerns over their future survivial. 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 (*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.

There is some indication that populations of native unionid populations could be recoverable in some open waters. The St. Lawrence River unionid fauna declined precipitously after the initial invasion of dreissenids. Recent work in parts of the St. Lawrence River has shown that unionid populations may persist though at greatly reduced numbers. After a period of time native mussel numbers have stabilized and reproduction is occurring, although body condition of the adults is still poor. The mechanism supporting this survival has not been determined, although no obvious "refugia" conditions seem to be present. One critical point of difference is that this part of the St. Lawrence River is one of the few areas where food competition with dreissenids and not biofouling was the main cause of death in the unionids.

In inland waters, large scale refugia can be provided by free-flowing rivers and streams due to the limitations of the dreissenid veliger cycle. Flowing water has limited persistent dreissenid colonization potential since the veligers require an average of 20-30 days to develop into the benthic stage and may end up flushing downstream out into the open lake. However, regulated rivers, i.e., those with reservoirs, may not provide refugia. Reservoirs with retention times greater than 20 to 30 days will allow veligers to develop and settle, after which the impounded populations will seed downstream reaches on an annual basis.

Pressures

Zebra and quagga mussel expansion is presently the main threat facing unionids in the Great Lakes drainage basin. Zebra and quagga 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.

While zebra and quagga mussels remain the most immediate threat to unionid survival in most of the Great Lakes, water quality problems associated with organic and inorganic pollutants, continuing changes in land use (e.g. increasing urban sprawl, growth of factory farms, etc.), climate change and the associated lowering of water levels, loss of fish hosts, dams, 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 and quagga mussels, should be documented, and they must be protected by all possible means from future disturbance.
- Research is needed to determine the mechanisms responsible for survival of unionids in the various refuge sites, and this knowledge should be used to predict the locations of other refugia and to guide their management.
- The environmental requirements of unionids need to be taken into account in wetland restoration projects.
- All avenues for educating the public about the plight of unionids in the Great Lakes should be pursued, as well as legislation for their protection. This includes ensuring that all species that should be listed are listed as quickly as possible.
- The principles of the National Strategy for the Conservation of Native Freshwater Mussels (The National Native Mussel Conservation Committee 1998) should be applied to the conservation and protection of the Great Lakes unionid fauna.

Acknowledgments

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Last Updated
State of the Great Lakes 2009

Lake Trout

Indicator #93

Overall Assessment

Status: **Mixed**
Trend: **Unchanging**
Rationale: **Factors used to determine status were the levels of natural reproduction observed, the survival of hatchery-reared fish after stocking, the level of mortality on adults from sea-lamprey and fishing, and the overall population trajectory. This limits harvest objectives in most lakes.**

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Improving
Rationale: Natural reproduction of both nearshore (lean) and offshore (siscowet) populations is widespread and supports all populations. Most stocking has been discontinued and fisheries are well managed. Sea lamprey mortality has been increasing.

Lake Michigan
Status: Poor
Trend: Unchanging/Deteriorating
Rationale: Survival of adult fish is declining in some areas from increased sea lamprey mortality. There is no evidence of significant natural reproduction. Fishing mortality is low.

Lake Huron
Status: Mixed
Trend: Improving
Rationale: Levels of natural reproduction continue to increase, adult abundance is stable to declining, and survival of stocked fish is low and declining. Fishing and sea lamprey mortality have declined since 2001 but have increased slightly during the last few years.

Lake Erie
Status: Mixed
Trend: Unchanging
Rationale: Sea lamprey mortality is high. A shift to a deepwater Lake Superior strain for stocking has appeared to improved post-release survival and overall population is increasing. Natural reproduction has not been observed.

Lake Ontario
Status: Mixed
Trend: Deteriorating
Rationale: Post-release survival of stocked fish is declining and the level of natural reproduction remains low.

Purpose

- To track the status and trends in lake trout populations
- 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 1.8 million kg (4 million pounds) from Lake Superior, 1.1 million kg (2.5 million pounds) from Lake Michigan, 0.9 million kg (2.0 million pounds) from Lake Huron and 50 thousand kg (0.1 million pounds) from Lake Erie. Lake Ontario has no specific yield objective but has a population objective of 0.5 to 1.0 million adult fish that produce 100,000 yearling recruits annually through natural reproduction.

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

Status of Lake Trout
Trends in the relative abundance of lake trout in each of the Great Lakes are displayed in Figure 1. Targets are set for most populations as these are perceived to be biologically important to increase the probability of natural reproduction. 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, and supports both onshore and offshore populations. Populations may be approaching historical levels, and stocking there has been largely discontinued. Trends of wild adult and large juvenile populations appear to be relatively stable (Fig. 1A). In Lake Huron, substantial and widespread natural reproduction was seen starting in 2004 following near collapse of the alewife population. Overall abundance of hatchery-reared fish has been declining since the 1990s due to declining survival of young hatchery fish (Fig. 1B). Populations of wild adult spawners are at or approaching target levels at selected refuge sites (Fig. 1C). In Lake Michigan (Fig. 1D), lakewide populations are below target levels in most areas, with no sustained natural reproduction. In Lake Erie, target abundances of all age groups and age 5+ fish are below target levels (Fig. 1E). Abundance of hatchery-reared adults was relatively high in Lake Ontario from 1986 to 1998, but declined by more than 30% in 1999 due to reduced stocking and poor survival of stocked yearlings since the early 1990s (Fig. 1F). Adult abundance again declined by 54% in 2005 likely due to ongoing poor recruitment and mortality from sea lamprey predation. Sustained natural reproduction, albeit at low levels, has also been occurring in Lake Ontario since the early 1990s.

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

Management Implications
Continued and enhanced sea lamprey control is required basin-wide to increase survival of lake trout to adulthood. New sea lamprey control options, which include pheromone systems that increase trapping efficiency and disrupt reproduction, are being researched and hold promise for improved control. Continued and enhanced control on exploitation is being improved through population modeling in the upper Great Lakes, and is now being applied on Lake Ontario. Stocking densities need to be increased in some areas, especially in Lake Michigan and possibly Lake Ontario. The use of alternate strains of lake trout from Lake Superior could be candidates for deep, offshore areas not colonized by traditional strains used for restoration. Introduction of such strains has been initiated in Lake Erie, will start soon in Lake Ontario and are being considered for Lake Michigan. Direct stocking of

eggs, fry, and yearling on or near traditional spawning sites should be used where possible to enhance colonization. The need to restore native forage fish, such as cisco and bloater, is gaining momentum and seen as an important requirement to aid in bringing lake trout back to self sustainability. This activity will require careful consideration of the transfer of diseases among lakes.

Comments from the author(s)

Reporting frequency should be every five years. Monitoring systems are in place, but in most lakes the measures do not directly relate to stated harvest objectives. Lake trout population objectives may need to be redefined as endpoints in units measured by the monitoring activities, and are being incorporated into restoration guides and plans. The data time series we present are based on important population targets that can be measured with current assessment activities.

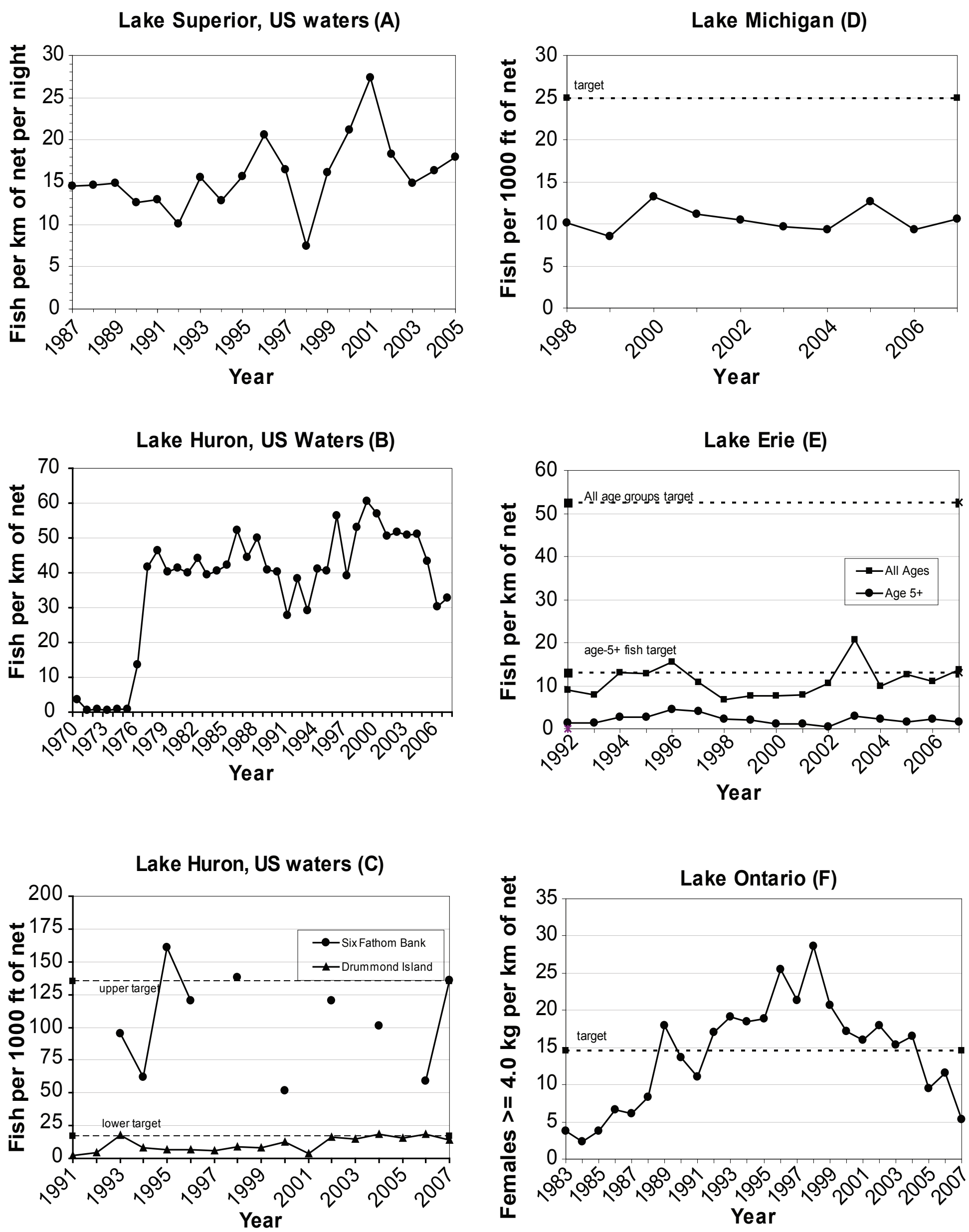

Figure 1: Relative abundance of lake trout in the Great Lakes.
The measurements reported vary from lake to lake, as shown on the vertical scale, and comparisons among lakes may be misleading. Overall trends over time provide information on relative abundances.
Source: Data sources are from biological assessments conducted cooperatively by state, federal, tribal and provincial agencies, and are largely contained in non-peered reviewed reports to the Great Lakes Fishery Commission, Lake Committees.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources				X		
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report				X		
Clarifying Notes: Data sources are from biological assessments conducted cooperatively by state, federal, tribal and provincial agencies, and are largely contained in non-peered reviewed reports to the Great Lakes Fishery Commission, Lake Committees.						

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Last Updated
State of the Great Lakes 2009

Benthos Diversity and Abundance

Aquatic Oligochaete Communities
Indicator #104

Overall Assessment

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

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Unchanging
Rationale: All sites had index values that ranged from 0 to 0.5, indicating oligotrophic conditions.

Lake Michigan
Status: Mixed
Trend: Unchanging/Deteriorating
Rationale: Most sites had index values that ranged from 0 to 0.5, indicating oligotrophic conditions. The two most southeastern nearshore sites changed from oligotrophic status in 2000, to mesotrophic or eutrophic status from 2001-2006.

Lake Huron
Status: Mixed
Trend: Unchanging
Rationale: Saginaw Bay was mesotrophic for six of the seven years examined. All other sites were oligotrophic.

Lake Erie
Status: Mixed
Trend: Unchanging/ Deteriorating
Rationale: Most sites were mesotrophic to eutrophic. Two western sites were oligotrophic to mesotrophic due to reduced numbers of oligochaetes. Sites in both the central and the eastern part of the lake have exhibited a general trend of increasing index values, although this has moderated in 2005-2006.

Lake Ontario
Status: Mixed
Trend: Unchanging
Rationale: Most sites were oligotrophic. The three southern-most nearshore sites varied from oligotrophic to eutrophic on a year-to-year basis. No overall trend was apparent.

Purpose

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

Ecosystem Objective

Benthic communities throughout the Great Lakes should retain species abundance and diversity typical for benthos in similar unimpaired waters and substrates. A measure of biological response to organic enrichment of sediments is based on Milbrink's (1983) Modified Environmental Index (MEI). This index was modified from Howmiller and Scott's (1977) Environmental Index. This measure will have wide applicability for nearshore, profundal, riverine, and bay habitats of the Great Lakes. This indicator supports Annex 2 of the Great Lakes Water Quality Agreement (United States and Canada 1987).

State of the Ecosystem

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

The use of Milbrink's index values to characterize aquatic oligochaete communities provided one of the earliest measures of habitat quality improvements (e.g., western Lake Erie). This index has been used to measure changing productivity in waters of North America and Europe and, in general, appears to be a reasonable measure of productivity in waters of all the Great Lakes (Figs. 1 and 2). The index values from sites in the upper lakes continue to be very low (less than 0.6), indicating an oligotrophic status for these areas. Index values from sites such as the nearshore areas of southeastern and east-central Lake Michigan and Saginaw Bay in Lake Huron, which are known to have higher productivity, exhibited higher index values that indicate mesotrophic (0.6 to 1.0) to eutrophic (greater than 1.0) conditions. Nearshore sites in southern Lake Ontario continued to be classified as mesotrophic to eutrophic, while offshore sites were oligotrophic. Sites in Lake Erie exhibited the highest index values; nearly all of them fell within the mesotrophic or eutrophic category (one site in western Lake Erie had low values characterized by low numbers of oligochaetes). Over most of the last seven years, a trend of increasing index values was observed for eastern Lake Erie.

Pressures

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

Management Implications

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

Comments from the author(s)

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

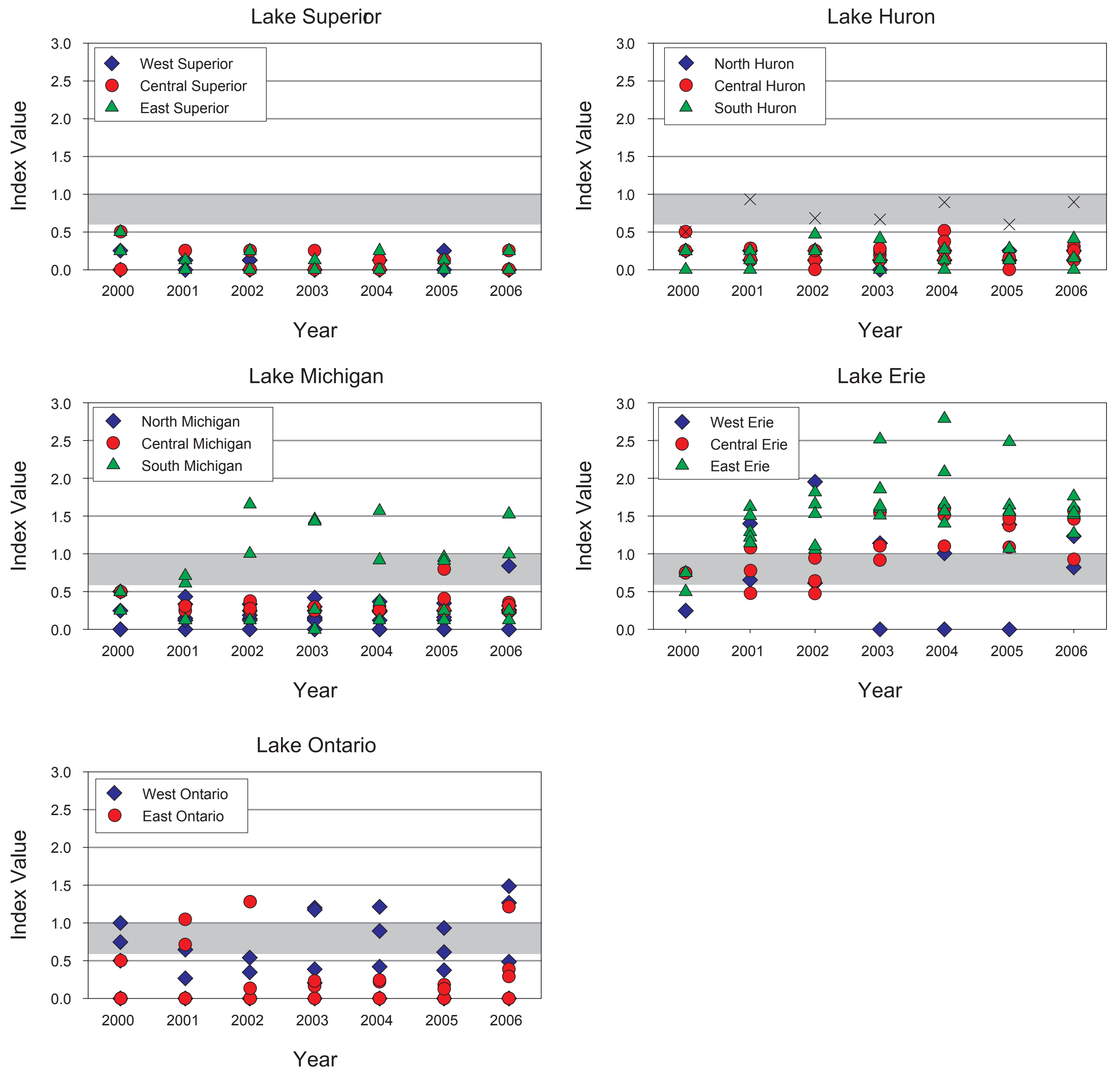

Figure 1. Scatter plots of index values for Milbrink's (1983) Modified Environmental Index, applied to data from GLNPO's 2000-2006 summer surveys.
Values ranging from 0-0.6 indicate oligotrophic conditions; values from 0.6-1.0 indicate mesotrophic conditions (shaded area); values above 1.0 indicate eutrophic conditions. Index values for the taxa were taken from the literature (Milbrink 1983, Howmiller and Scott 1977); immature specimens were not included in any calculations. Data points represent average of triplicate samples taken at each sampling site.
Source: U.S. Environmental Protection Agency, 2000-2006.

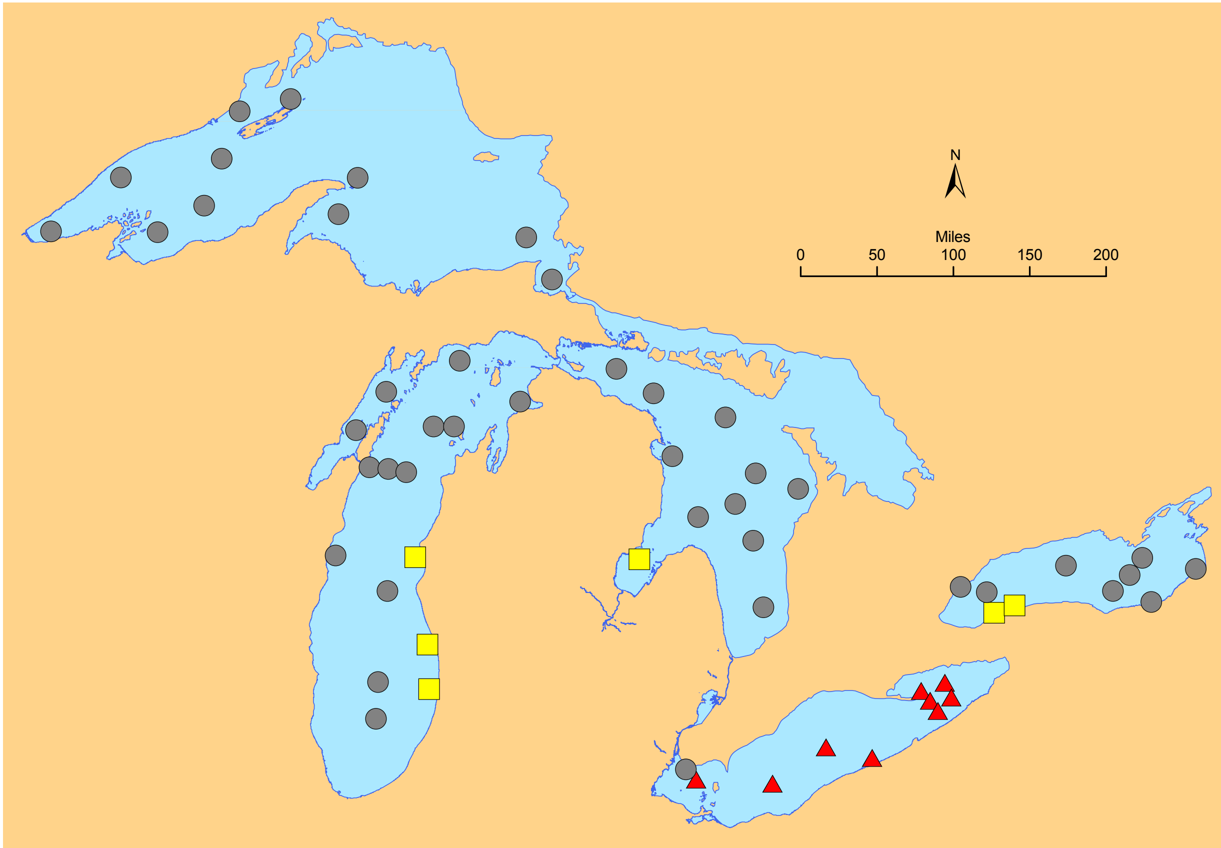

Figure 2. Map of the Great Lakes showing trophic status based on Milbrink's (1983) Modified Environmental Index using the oligochaete worm community. Data taken from 2006. Gray circles = oligotrophic; yellow squares = mesotrophic; red triangles = eutrophic.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

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Sources

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Last Updated

State of the Great Lakes 2009

Phytoplankton Populations

Indicator #109

This indicator report was last updated in 2003.

Overall Assessment

Status: **Mixed***
Trend: **Undetermined**
**Note: This assessment is based on historical conditions and expert opinion. Specific objectives or criteria have not been determined.*

Lake-by-Lake Assessment

Separate lake assessments were not included in the last update of this report.

Purpose

- To directly assess phytoplankton species composition, biomass, and primary productivity in the Great Lakes
- 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 (Fig. 1). The timing of this decline suggests the possible impact of zebra mussels. In Lake Michigan, a significant increase in the size of summer diatom populations occurred during the 1990s. This was most likely due to the 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

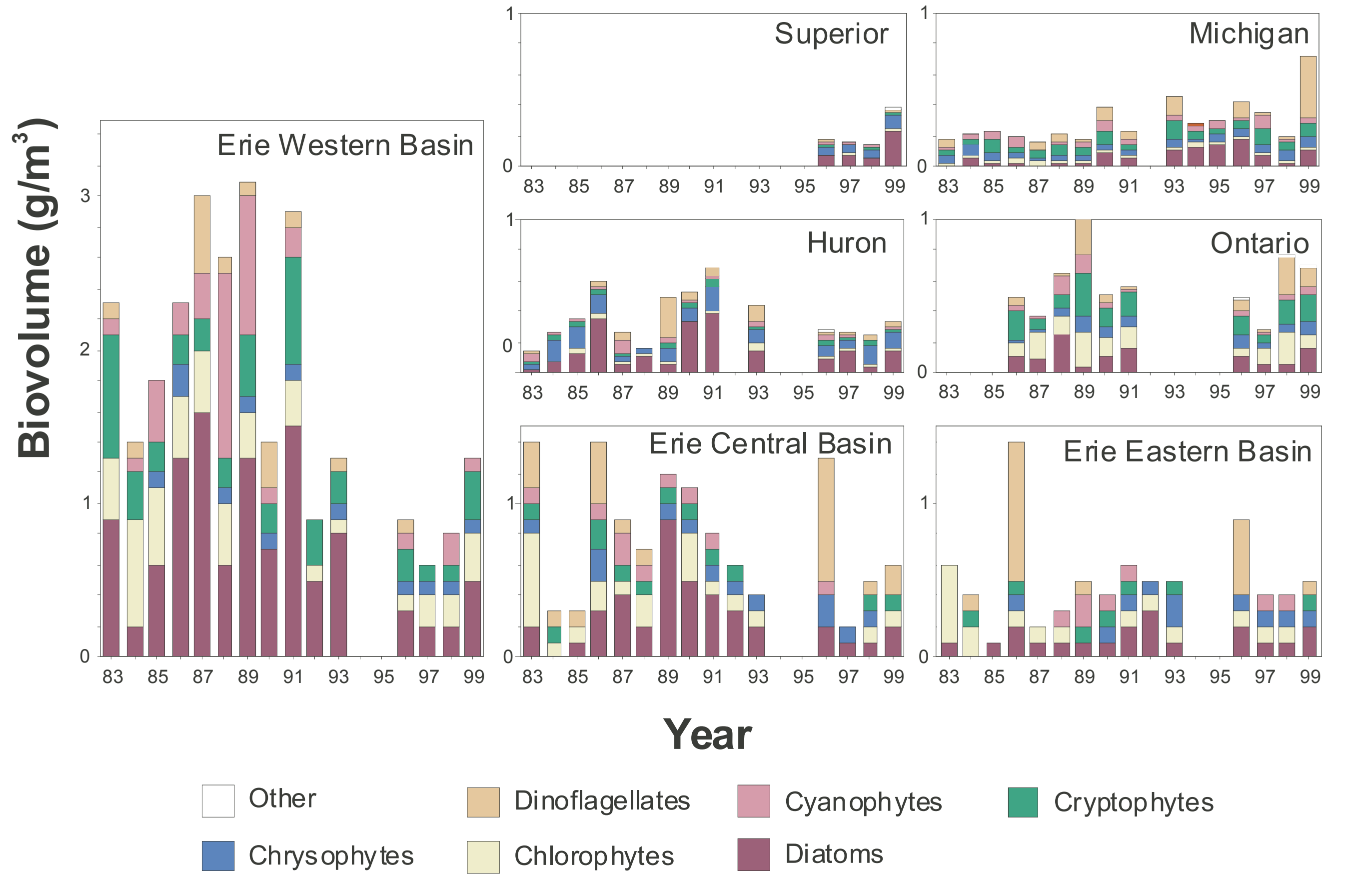

Figure 1. Trends in phytoplankton biovolume (g/m³) and community composition in the Great Lakes 1983-1999. Samples were collected from offshore, surface waters during August.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office.

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.

Comments from the author(s)

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”.

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

Last Updated
State of the Great Lakes 2003

Phosphorus Concentrations and Loadings

Indicator #111

Overall Assessment

Status: **Open Lake - Mixed; Nearshore - Poor**
Trend: **Open Lake - Mixed (Improving or Unchanging); Nearshore - Undetermined**
Rationale: **Strong efforts that began in the 1970s to reduce phosphorus loadings have been successful in maintaining or reducing nutrient concentrations in the Great Lakes, although high concentrations still occur locally in some embayments, harbors and nearshore areas. Conditions in nearshore regions are highly dynamic, therefore an overall trend cannot be defined.**

Lake-by-Lake Assessment

Lake Superior
Status: Open Lake - Good; Nearshore - Not Assessed
Trend: Open Lake - Unchanging; Nearshore - Undetermined
Rationale: Average phosphorus concentrations in the open waters remain at or below expected levels.

Lake Michigan
Status: Open Lake - Good; Nearshore - Poor
Trend: Open Lake - Improving; Nearshore - Undetermined
Rationale: Average phosphorus concentrations in the open waters are at or below expected levels. Concentrations may exceed guidelines in nearshore waters for at least part of the growing season.

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

Lake Erie
Status: Open Lake – Fair/Poor; Nearshore - Poor
Trend: Open Lake - Unchanging; Nearshore - Undetermined
Rationale: Phosphorus concentrations in the three basins of Lake Erie fluctuate from year to year and frequently exceed target concentrations. Extensive lawns of *Cladophora* are common place over the nearshore lakebed in parts of Eastern Lake Erie and are suggestive of phosphorus levels supportive of nuisance levels of algal growth.

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

Purpose
- To assesses total phosphorus levels in the Great Lakes
- 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 Lake Superior, Lake Huron and Lake Michigan; to maintain algal biomass below that of a nuisance condition in Lake Erie and Lake 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). 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 anthropogenic sources. Detergents, sewage treatment plant effluent, agricultural runoff and industrial sources have historically introduced large amounts into the Great Lakes.

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

Researchers involved with phosphorus load estimation from tributaries to Lake Erie and Lake Michigan have noted that phosphorus loads may be increasing after a long period of decrease, and that an increasing proportion of the phosphorus is an available, dissolved form. Both these observations have important implications, particularly to the nearshore. More phosphorus entering the nearshore, in a form easily used by algae, could lead to more algal blooms in the lakes.

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

Similarly, phosphorus concentrations may exceed the guidelines in Lake Michigan nearshore waters for at least part of the growing season. Waters near Lake Michigan's eastern shoreline, when sampled in June, 2004, had a median concentration of 9 µg/L. Summer sampling at the same locations yielded a median concentration of 6 µg/L, but a number of sampling locations were at or above the 7 µg/L guideline. By comparison, the average open water concentration during the spring of 2004 was 3.7 µg/L. *Cladophora* growth is a problem on much of this shoreline.

In parts of eastern Lake Erie and Lake Ontario, extensive lawns of *Cladophora* are commonplace and are suggestive of phosphorus levels supportive of nuisance levels of algal growth (Higgins *et al.* 2005, Wilson *et al.* 2006). Phosphorus levels in the Canadian

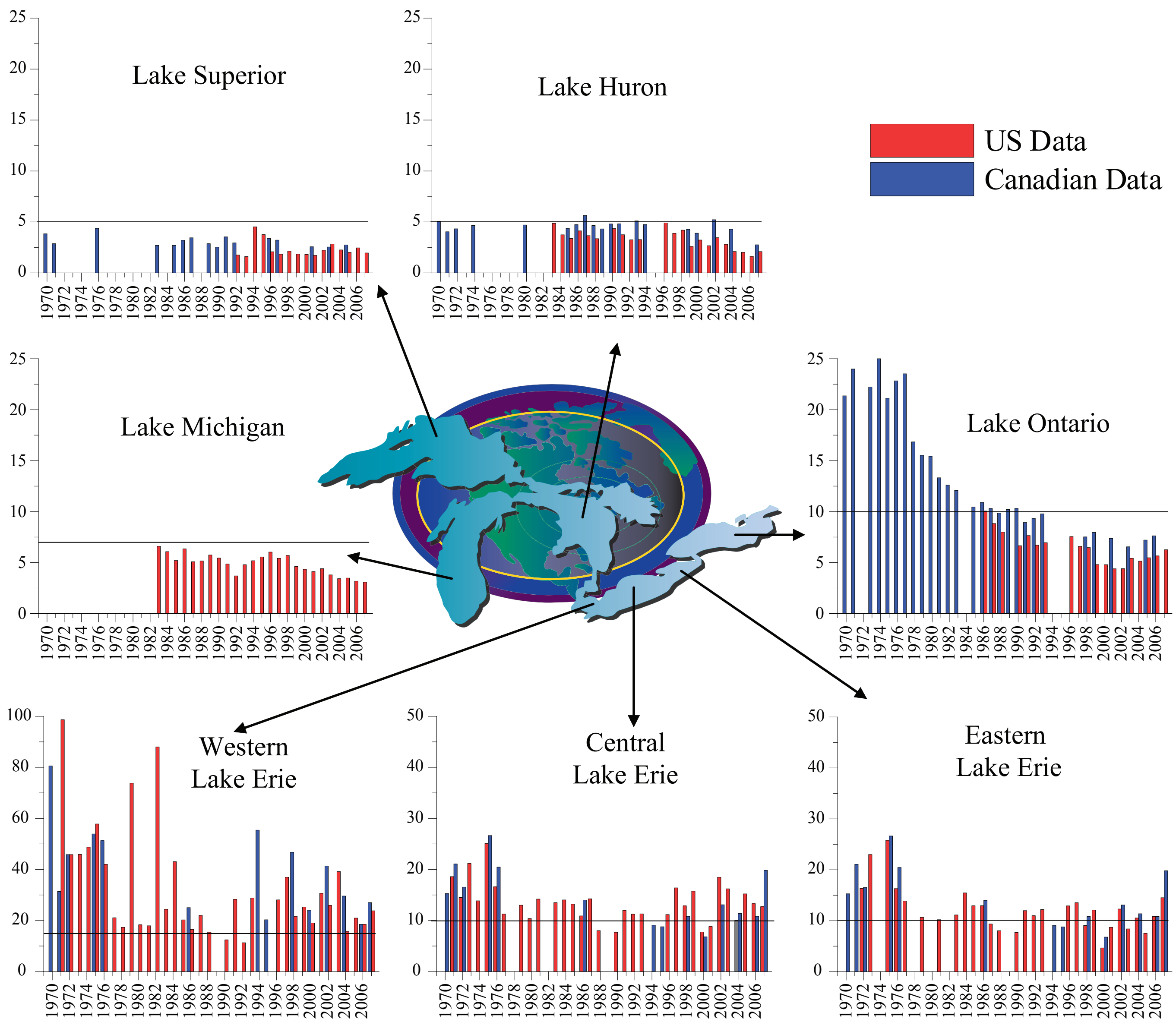

Figure 1. Total Phosphorus Trends in the Great Lakes (µg/L), 1970 to 2007. Blanks indicate no sampling. Horizontal line on each graph represents the expected phosphorus concentration in each lake if the annual phosphorus loading targets, as listed in the Great Lakes Water Quality Agreement, are maintained. Environment Canada data (white bars) are averages of spring, surface measurements at open lake sites. U.S. Environmental Protection Agency data (black bars) are averages of spring measurements, all depths at open lake sites.
Source: Water Quality Monitoring and Surveillance Division, Environment Canada and Great Lakes National Program Office, U.S. Environmental Protection Agency.

nearshore of eastern Lake Erie and Lake Ontario are periodically elevated above the basin guideline of 10 µg/L. However, efforts to achieve integrated nearshore assessments of phosphorus levels or to relate phosphorus levels to growth of *Cladophora* are difficult because of the highly dynamic nature of water quality in nearshore areas. Phosphorus concentrations in the nearshore tend to be highly variable due to the influences of tributaries and other shore-based discharges, weather, biological activity and lake circulation. The impacts of recycling of phosphorus in the Lake Ontario nearshore by invasive Dreissenid (i.e., zebra and quagga) mussels. Dreissenid mussels filter large volumes of water, and in doing so they decrease the concentration of total phosphorus in the water column through the removal of particles, but they excrete soluble (i.e., dissolved) phosphorus, thereby increasing the availability of phosphorus that can be readily utilized by algae such as *Cladophora*.

Pressures

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

Management Implications

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

The data needed to support loadings calculations have not been collected since 1991 in all lakes except Lake Erie, which has loadings information up to 2002, and Lake Michigan with information for 1994 and 1995. Efforts to do so are beginning for Lakes Superior, Michigan, Huron and Ontario, and have begun for Lake Erie In addition to estimates of total phosphorus loads, efforts should be undertaken to determine the loads of available phosphorus that are now entering the Great Lakes. This unexpected change in the components of the phosphorus load may be having an influence on the observed *Cladophora* and cyanobacteria growth.

The surveillance of phosphorus concentrations in the Great Lakes is ongoing and the data are considered to be reliable. Enhanced and coordinated monitoring of nearshore sites is being conducted through Cooperative Monitoring and Collaborative Science Initiatives. The recent reappearance of *Cladophora* in some areas of the Great Lakes strengthens the need for nearshore measurements to better understand the very dynamic nearshore environment.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated

State of the Great Lakes 2009

Contaminants in Young-of-the-Year Spottail Shiners

Indicator #114

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Rationale: **Although levels of PCBs in forage fish have decreased below the guideline at many sites around the Great Lakes, PCB levels remain elevated at some sites. As well, DDT levels in forage fish have declined but remain above the guideline at most of the Great Lakes locations.**

Lake-by-Lake Assessment

Lake Superior
Status: Mixed
Trend: Improving
Rationale: PCB concentrations in Lake Superior forage fish have declined over the period of record and are currently below the guideline at all sites. DDT levels have declined to just below the guideline.

Lake Michigan
Status: Not Assessed
Trend: Not Assessed
Rationale: Juvenile fish have not been sampled from Lake Michigan by the Ontario Ministry of the Environment.

Lake Huron
Status: Mixed
Trend: Improving
Rationale: PCB levels in Lake Huron forage fish have remained static or declined over the period of record and are currently at or below the guideline. DDT levels have declined but were elevated at Collingwood Harbour in the last sampling year (2002).

Lake Erie
Status: Mixed
Trend: Improving
Rationale: PCB levels in Lake Erie forage fish have declined to levels at or slightly above the guideline. DDT levels have also declined over the period of record but remain at or slightly above the guideline.

Lake Ontario
Status: Mixed
Trend: Improving
Rationale: PCB levels in Lake Ontario forage fish have declined significantly over the period of record and the most recent levels are generally between 100 and 200 ng/g. DDT levels in forage fish declined considerably at some sites in the late 1970s, but since that time have remained relatively unchanged. Current levels remain above the guideline at all sites. Mirex levels have also declined and have remained below the detection limit since the early 1990s.

Purpose

- To assess the levels of persistent bioaccumulative toxic (PBT) chemicals in young-of-the-year spottail shiners or other species when spottail shiners are unavailable
- To infer local areas of elevated contaminant levels and potential harm to fish-eating wildlife
- 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 (GLWQA; United States and Canada, 1987), the New York State Department of Environmental Conservation (NYSDEC) Fish Flesh Criteria for the protection of piscivorous wildlife (Newell *et al.*, 1987), and the Canadian Environmental Quality Guidelines (Canadian Council of Ministers of the Environment (CCME), 2001) are used as acceptable guidelines for this indicator. Contaminants monitored in forage fish by the Ontario Ministry of Environment (OMOE) and their respective guidelines are listed in Table 1.

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

Table 1. Tissue Residue Criteria for various organochlorine chemicals or chemical groups for the protection of wildlife consumers of aquatic biota.
*IJC Aquatic Life Guideline (IJC 1988); †Canadian Environmental Quality Guidelines (CCME 2001); all other guidelines from NYSDEC Fish Flesh Criteria (Newell *et al.* 1987). Guidelines based on mammals and birds.

State of the Ecosystem

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

With the incorporation of the CCME guidelines, the total dichloro-diphenyl-trichloroethane (DDT) tissue residue criterion is exceeded at most locations. After total DDT, polychlorinated biphenyls (PCB) is the contaminant most frequently exceeding the guideline. Mirex was historically detected and exceeded the guideline at Lake Ontario locations. However, mirex concentrations over the past 10 to 20 years have been below detection. Other contaminants listed in Table 1 are often not detected, or are present at levels well below the guidelines.

<u>Lake Superior</u>

Trend data were examined for four locations in Lake Superior: Mission River, Nipigon Bay, Jackfish Bay and Kam River (Fig. 1). Recent data are not available for Jackfish Bay.

PCB concentrations were generally lower at Lake Superior sites compared to the other lakes. The highest PCB concentrations in Lake Superior were found at Mission River in 1983 (139 ng/g). Otherwise, mean PCBs were below the guideline (100 ng/g). The highest concentrations of PCBs at the other three Lake Superior sites also occurred in 1983 and ranged from 51 ng/g at Nipigon Bay to 89 ng/g at Jackfish Bay. Juvenile fish collected from Mission River, Nipigon Bay and the Kam River in 2005 contained very low PCBs (below detection, 42 ng/g and 28 ng/g, respectively).

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 reached 64 ng/g (based only on one composite sample), the highest concentration observed in juvenile fish from any Lake Superior site to date. At Jackfish Bay and the Kam River, total DDT levels were below the guideline each year, except for 1990 at the Kam River when levels rose to 35 ng/g (based on only two composite samples).

Juvenile fish collected from Mission River, Nipigon Bay and the Kam River in 2005 contained DDT levels below the guideline, indicating that this compound may no longer be of concern for the lake.

Lake Michigan

Juvenile fish have not been sampled from Lake Michigan by the OMOE.

Lake Huron

Trend data are available for three Lake Huron/Georgian Bay sites: Collingwood Harbour, Nottawasaga River and the Saugeen River (Fig. 2). At Collingwood Harbour, the highest PCB concentrations were found when sampling began in 1987 (206 ng/g). Since then, PCB concentrations have remained near or just below the guideline. At the Nottawasaga River the highest concentration of PCBs was observed in 1977 (90 ng/g). Concentrations declined to less than the detection limit by 1987 and in 2002 were detected at very low levels. Levels of PCBs in the Saugeen River were also highest in 1977 (182 ng/g) and have declined since 1980 to below the guideline.

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 levels since 1977 when concentrations peaked at 106 ng/g. In 2002, levels were below the guideline. At the Saugeen River site, DDT has declined from 62 ng/g in 1977 to below the guideline in 2002.

Lake Erie

Trends of contaminants in spottail shiners were examined for four locations in Lake Erie: Big Creek, Grand River, Thunder Bay Beach and Leamington (Fig. 3). Overall, the trends show higher concentrations of PCBs in the early years (1970s) with a

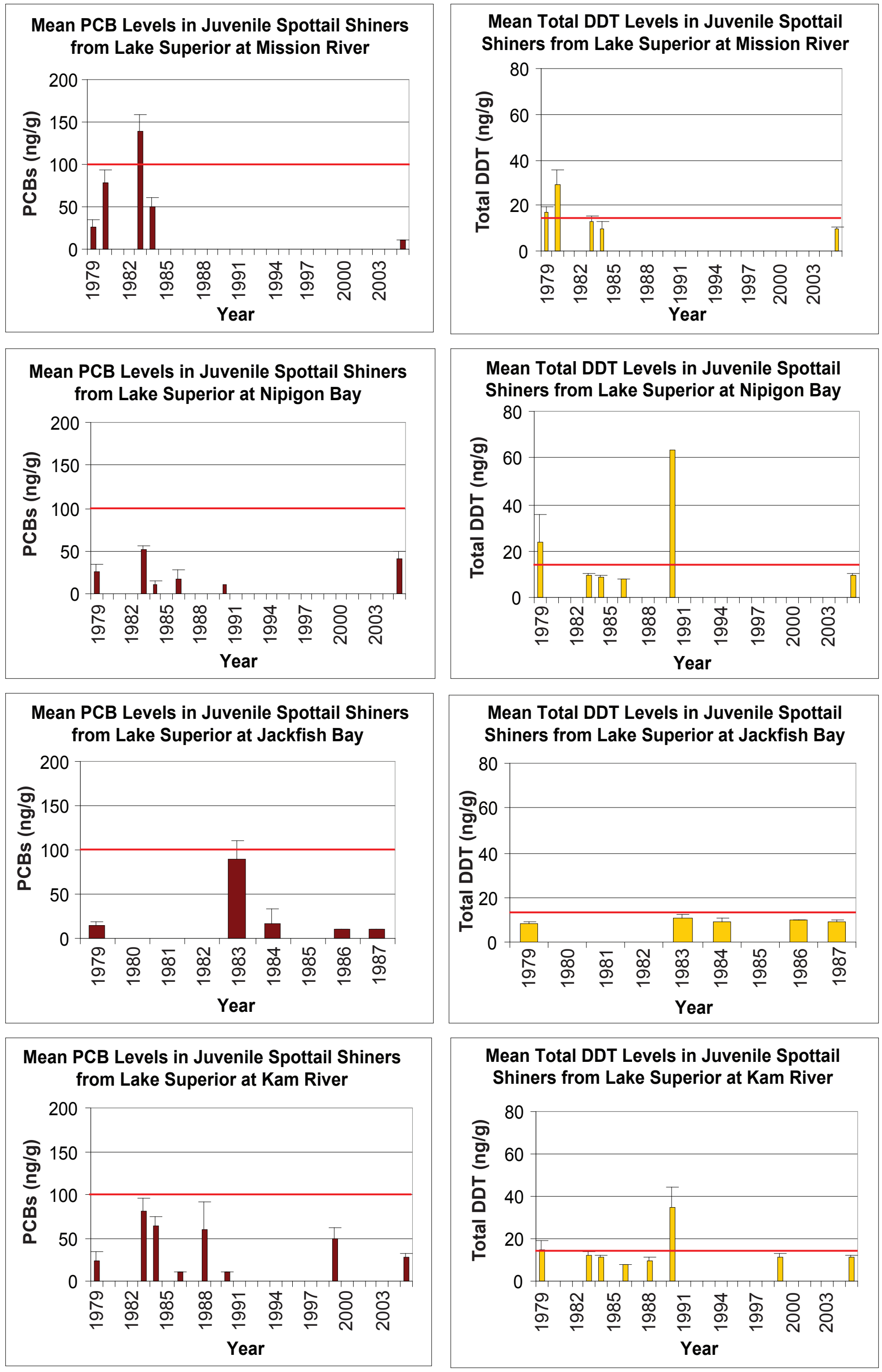

Figure 1. PCB and total DDT levels in juvenile spottail shiners from four locations in Lake Superior.
The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean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

decline over time. At Big Creek, PCB concentrations were elevated (greater than 300 ng/g in most years) until 1985, but since then concentrations have remained near the guideline (100 ng/g). At the Grand River and Thunder Bay Beach locations, PCB concentrations exceeded the guideline slightly in the late 1970s but did not exceed 200ng/g throughout the period of record. In recent years, PCB concentrations have remained below the GLWQA guideline of 100 ng/g at these two sites. At Leamington, PCB concentrations were considerably higher than at the other Lake Erie sites. Although they declined from 888 ng/g in 1975 to 204 ng/g in 2001, the concentrations exceeded the guideline in all years except for a period in the early to mid-1990s. In the most recent collection (2004), levels have declined to 136 ng/g,, which only marginally exceeds the GLWQA guideline.

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

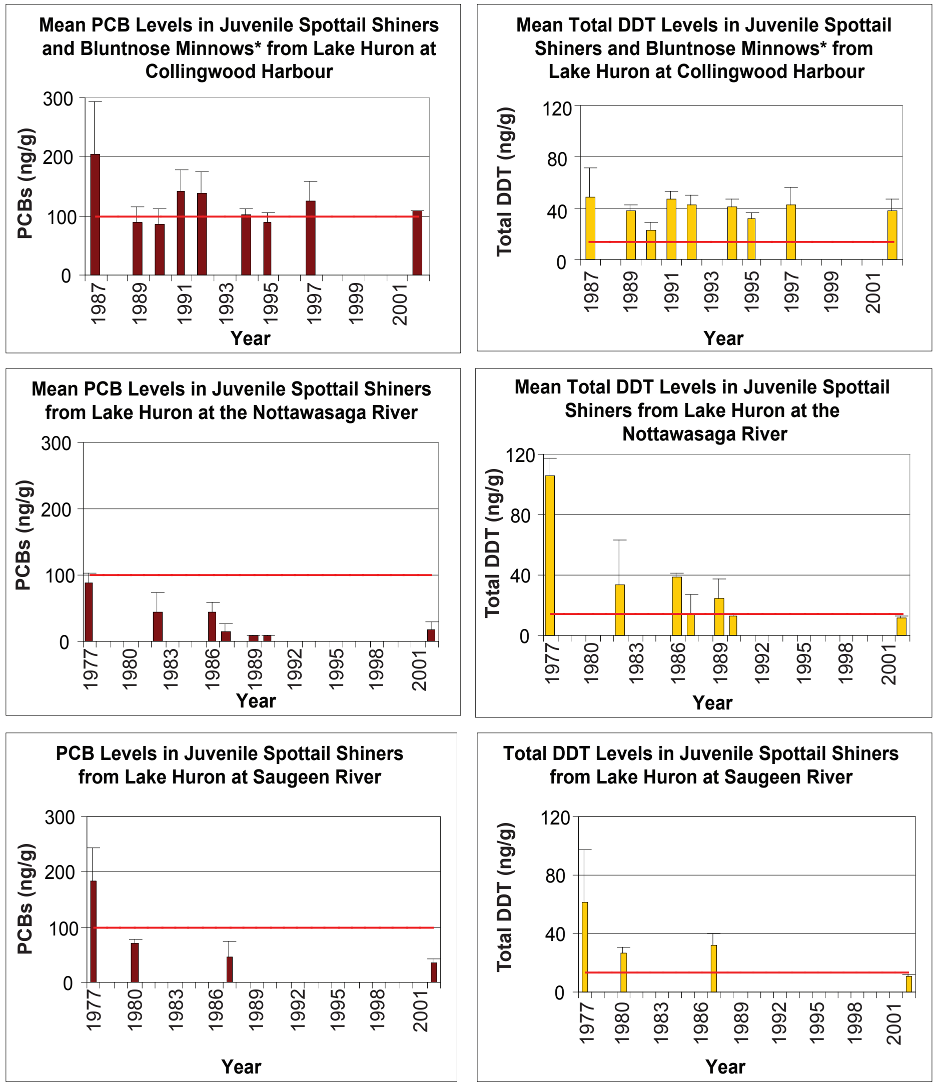

Figure 2. PCB and total DDT levels in juvenile spottail shiners and bluntnose minnows from three locations in Lake Huron.
The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration. Total DDT is the sum of the metabolites o,p-DDT, p,p'-DDT, p,p'-DDD and p,p'-DDE.
Source: Ontario Ministry of the Environment.

Lake Ontario

Contaminant concentrations from five sites were examined for trends: Twelve Mile Creek, Burlington Beach, Bronte Creek, Credit River and the Humber River (Fig. 4). PCBs, total DDT and mirex were generally higher at these (and other Lake Ontario) locations than elsewhere in the Great Lakes. PCBs at all locations were highest in the late 1970s, ranging from approximately 2 to 30 times the guideline. The maximum concentrations of PCBs were found at the Humber River in 1978 (2938 ng/g). In recent years, PCBs at these five sites have generally ranged from 100 to 200 ng/g, with the exception of Twelve Mile Creek, which has been below the guideline. PCBs were below the detection limit in the most recent sample from the Credit River (1998), a considerable decline from the year before (104 ng/g). This decline may be an anomaly and should be confirmed with continued monitoring.

After a significant decrease in the late 1970s at Burlington Beach, the Credit River and the Humber River, DDT levels have remained relatively unchanged. Historical DDT levels at Twelve Mile Creek and Bronte Creek were not as high as at the other three sites, and have remained relatively unchanged over the period of record. The maximum reported concentration of DDT was at the Humber River in 1978 (443 ng/g). Current DDT concentrations exceed the guideline at all sites. Mirex levels were historically elevated in juvenile fish from Lake Ontario, especially at Twelve Mile Creek and the Credit River. The maximum mean concentration was 37 ng/g at the Credit River in 1987. Since 1993, mirex has been below the detection limit at all five locations and is no longer a concern.

Pressures

New and emerging contaminants, such as brominated flame retardants may apply new pressures on Great Lakes water quality, however more research is necessary for the development of tissue residue guidelines for these contaminants.

Management Implications

For those contaminants that exceed the wildlife protection guidelines, additional remediation efforts may be required. Continued monitoring is essential to determine the status of contaminants in forage fish from the Great Lakes, as contaminants concentrations can be variable in the short-term and may not necessarily be indicative of a trend.

Comments from the author(s)

Organochlorine contaminants have declined in juvenile fish throughout the Great Lakes. However, regular monitoring should continue for all of these areas to determine if levels are below wildlife protection guidelines. Analytical methods should be improved to accommodate revised guidelines and to include additional contaminants such as dioxins and furans, dioxin-like PCBs and brominated flame retardants. Historical data do not include toxaphene concentrations. Since this contaminant has been responsible for consumption restrictions on sport fish from Lakes Superior and Huron in the past (Ontario Ministry of the Environment (OMOE), 2005), it is recommended that analysis of this contaminant be included in any future biomonitoring studies.

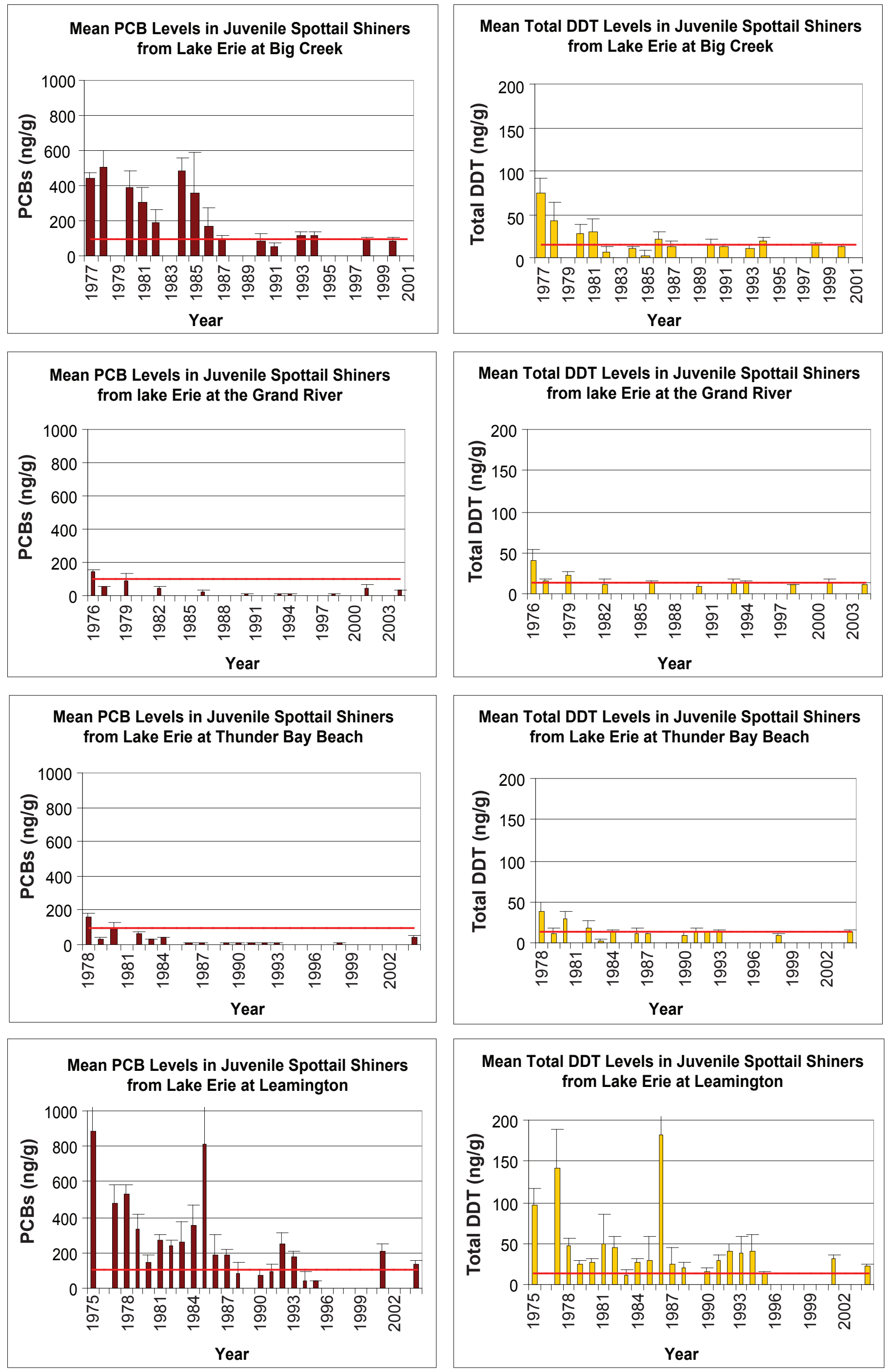

Figure 3. PCB and total DDT levels in juvenile spottail shiners from four locations in Lake Erie.
The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.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

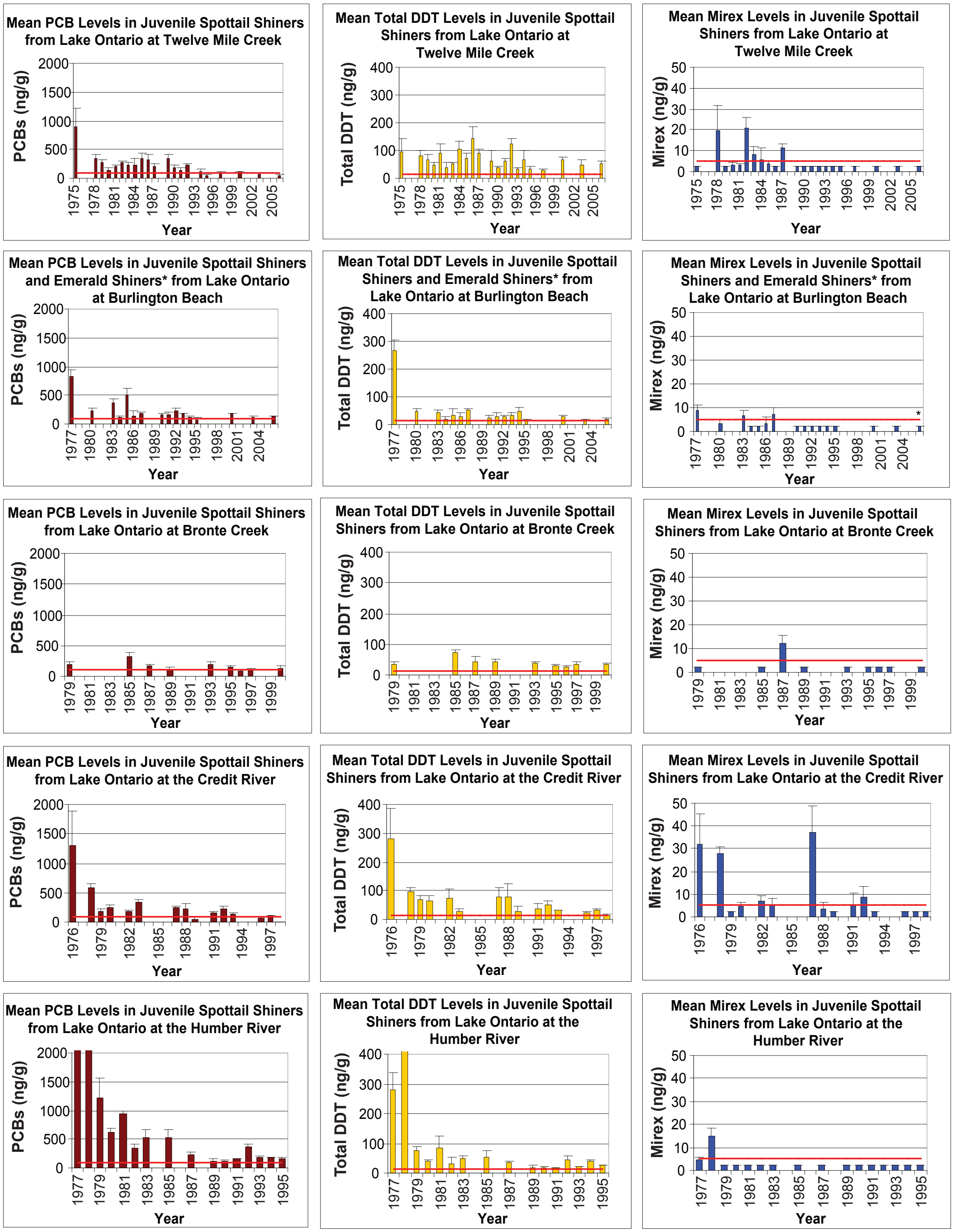

Figure 4. PCB, mirex and total DDT levels in juvenile spottail shiners and emerald shiners from five locations in Lake Ontario. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline for PCBs and total DDT. For mirex, the red line indicates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

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

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments
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Last Updated

State of the Great Lakes 2009

Contaminants in Colonial Nesting Waterbirds

Indicator #115

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Rationale: **Overall, most contaminants have declined substantially (more than 90%) since first measured. Spatially, in Lakes Erie and Huron, there is great variation in contaminant concentrations among monitor sites within the same lake. Temporally, up to 2007, 50.8% of concentrations of eight major contaminants at all colonies (120 comparisons) were declining as fast or faster than they did in the past; this is a decrease from what was reported in 2006 (down from >70%). Simultaneously, 43.4% were declining more slowly than previously.**

Lake-by-Lake Assessment

Lake Superior

Status: Good
Trend: Improving
Rationale: For seven contaminants that have been measured since the program started in 1974 (PCBs, DDE, HCB, HE, mirex, dieldrin and TCDD), the two herring gull egg monitoring sites in Lake Superior showed average declines of 90.4% and 94.8% between 1974 and 2007. Both sites ranked among the lowest for concentrations of seven major compounds among the 15 monitoring sites. The temporal pattern at the two sites showed 50% of colony-contaminant comparisons declining as fast as or faster than previously and 37.5% declining more slowly than previously.

Lake Michigan

Status: Mixed
Trend: Improving
Rationale: For seven contaminants that have been measured since the program started in 1974, the two herring gull egg monitoring sites showed an average decline of 96% between 1974 and 2007. Eggs from one of the Lake Michigan sites ranked as the 3rd most contaminated among the 15 monitoring sites. Eggs from the other site ranked much lower (9th). The temporal pattern for the two sites showed 75% of the colony-contaminant comparisons declining as fast as or faster than previously and 25% declining more slowly than previously.

Lake Huron

Status: Mixed
Trend: Improving
Rationale: Herring gull eggs from two of three monitoring sites in Lake Huron were relatively free of contaminants. The 3rd site, in Saginaw Bay, had the most contaminated gull eggs among all sites tested and reduced the overall status of this indicator in Lake Huron. The three sites showed average contaminant declines of 85.6% to 96.8% in gull eggs in 2007. Two of three sites ranked among the lowest for concentrations for seven major compounds among 15 sites. The temporal pattern at the three sites showed 70.8% of colony-contaminant comparisons declining as fast as or faster than previously and 20.8% declining more slowly than previously.

Lake Erie

Status: Mixed

Trend: Improving

Rationale: Of the two monitoring sites in Lake Erie, the most easterly, at Port Colborne, had the least-contaminated gull eggs of all 15 sites tested. Eggs from Middle Island, in the Western Basin, were considerably more contaminated. The two sites showed average contaminant declines of 78.4% and 90.2% in gull eggs in 2007. Eggs from Middle Island were in the mid-range and those from Port Colborne were the lowest for contaminants. The temporal pattern at the two sites showed 31.2% of colony-contaminant comparisons declining as fast as or faster than previously and 56.3% declining more slowly than previously.

Lake Ontario

Status: Mixed

Trend: Improving

Rationale: Eggs from the three Lake Ontario herring gull monitoring sites showed average declines of 88.9% to 94.8% in 2007. The three sites ranked among the highest eight for concentrations of contaminants in gull eggs. Temporally, 33.3% of colony-contaminant comparisons were declining as fast as or faster than previously while 62.5% were declining more slowly.

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
- 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 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 (HGEMP) is the longest continuously running annual wildlife contaminants monitoring program in the world (since 1974). It determines concentrations of up to 20 organochlorines, 65 polychlorinated biphenyl (PCB) congeners and 53 polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF) congeners, as well as 16 brominated diphenyl ether (BDE) congeners (Braune *et al.* 2003).

The primary factors used to assess the status and trends of contaminants in herring gull eggs were: 1) the change in contaminant concentrations in herring gull eggs between baseline levels (usually from 1974) and levels observed most recently in 2007 (Canadian Wildlife Service (CWS) unpublished); 2) the overall ranking of contaminant concentrations at the 15 Great Lakes herring gull egg monitoring sites (Weseloh *et al.* 2006); and 3) the direction and relative slope of the change-point regression line calculated for each compound at each site (Pekarik and Weseloh 1998, Weseloh *et al.* 2003, 2005, CWS unpublished).

Status of Contaminants in Colonial Waterbirds

The HGEMP has provided researchers and managers with a powerful tool (a 34-year database) to evaluate changes in contaminant concentrations in Great Lakes wildlife (Fig. 1). The extreme longevity of the egg database makes it possible to calculate temporal trends in contaminant concentrations in wildlife and to look for significant changes within those trends. The database shows that most contaminants in gull eggs have declined 90% or more since the program began in 1974 (Fig. 2). In 2007, PCBs, hexachlorobenzene (HCB), dichlorodiphenyl-dichloroethene (DDE), heptachlor epoxide (HE), dieldrin, mercury, mirex and 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) levels measured in eggs from the 15 Annual Monitoring Colonies (Fig. 3) were analyzed for temporal trends (total of 120 comparisons). Analysis showed that in 50.8% of cases (61 of the 120 comparisons), the contaminants were decreasing as fast as or faster in recent years than they had in the past. This was interpreted as a positive sign. In 43.4% of cases (52 of the 120 comparisons), contaminants were decreasing more slowly than they had in the past (calculated from Bishop *et al.* 1992, Pettit *et al.*1994, Pekarik *et al.*1998, and Jermyn-Gee *et al.* 2005, as per Pekarik and Weseloh 1998). This is viewed as a negative sign. HCB showed the most frequent reduction in their rates of decline. This represents a notably increase in the percent of cases showing a slow down in their rate of decline. At the time of this report, the reason(s) for this increase are not known. The overall decline in contaminant concentrations in gull eggs, however, may not be due wholly to a decrease in contaminants in the environment. Changes in food web dynamics, including the gulls' diet may be playing a role in some of these declines (Hebert *et al.* 2008).

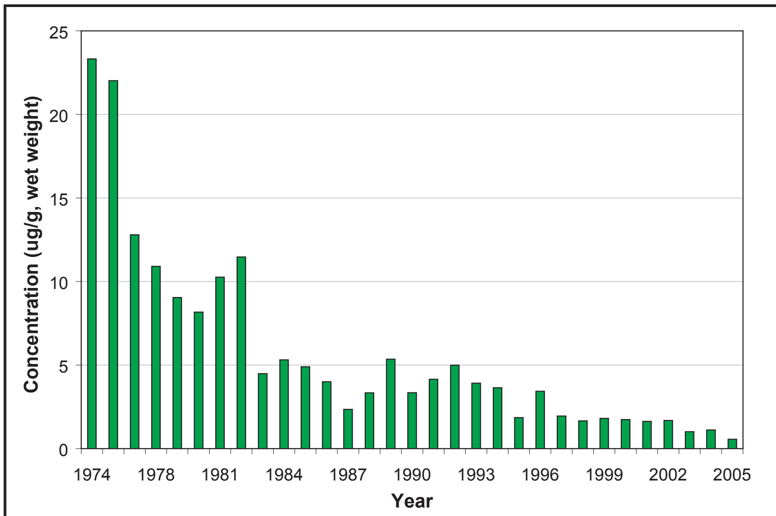

Figure 1. Annual concentration of DDE in Herring Gull eggs, Toronto Harbour, 1974-2005.
Source: Environment Canada, Herring Gull Monitoring Program.

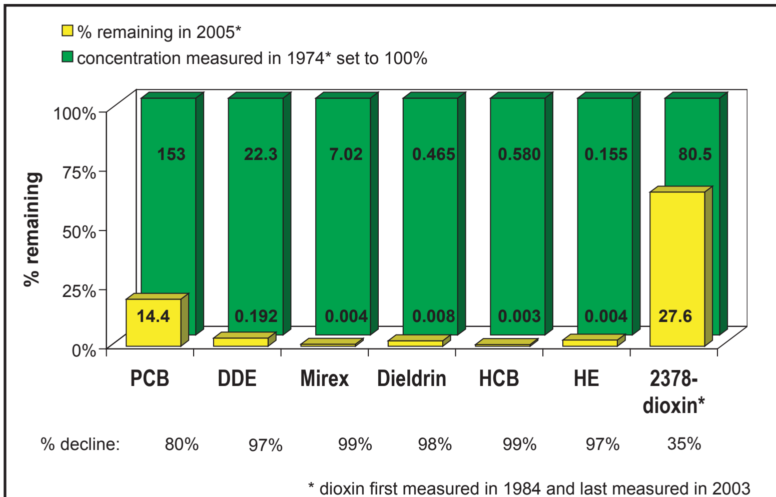

Figure 2. Mean contaminant concentrations and percent decline of 7 contaminants in Herring Gull eggs from year of first analysis to present, Middle Island, Lake Erie. Concentrations in µg/g wet weight except for dioxin in pg/g wet weight.
Source: Environment Canada, Herring Gull Monitoring Program.

The sole exception to these declining herring gull egg contaminant concentrations appears to be brominated diphenyl ethers (BDEs). These compounds, which are used as fire retardants in plastics, furniture cushions, etc., increased dramatically in gull eggs during 1981-2000 (Norstrom *et al.* 2002). Recent data showed a combined 3.9% decline for the 15 monitoring sites from 2000 to 2003, but a 25.3% increase from 2000 to 2005 (CWS, unpublished data); data from 2007 were not available at the time of this report.

Another aspect of annually-monitored contaminant levels in herring gull eggs is the year-to-year variability in contaminant concentrations depicted in Figures 1 and 4. In tracking 32 years of analyses, PCB concentrations declined in 65.6% of the years and increased in 34.4%; obviously the declines were of greater magnitude than the increases (Fig. 1). In examining PCB concentrations at all 15 annual monitor colonies from 2005 to 2007, concentrations declined at 33.7% of the sites, increased at 60.0%, and showed no change at the remainder (Fig. 4). Annual fluctuations like these, including both short-term increases and decreases, are part of current contaminant patterns.

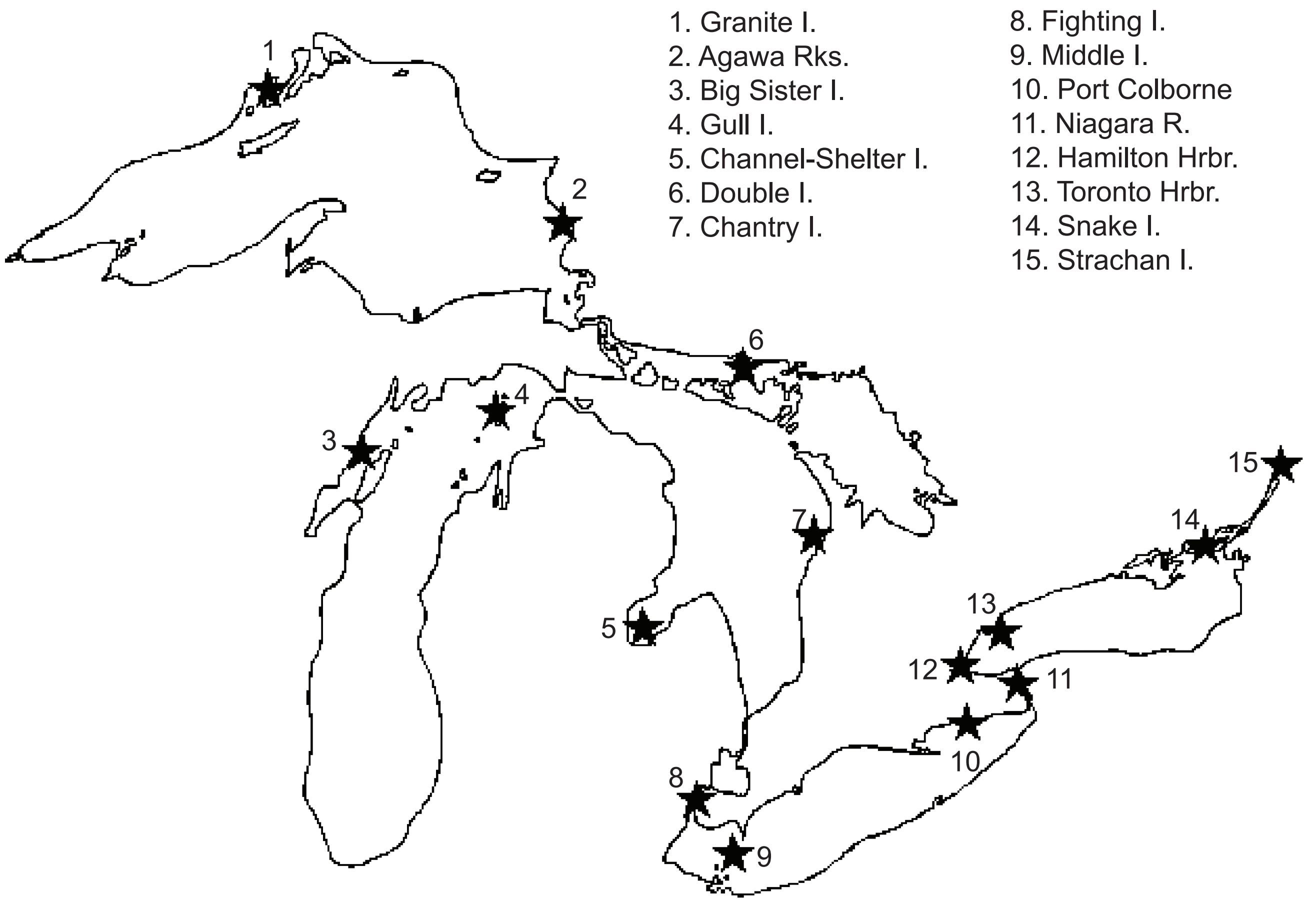

Figure 3. The distribution and locations of the 15 Herring Gull Annual Monitoring Colonies.
Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service.

In terms of gross ecological effects of contaminants on colonial waterbirds, most species appear to have recovered from historically-observed problems such as eggshell thinning, failed reproductive success and population declines. Populations of most species have increased over the past 25-30 years, (Fig. 5) (Blokpoel and Tessier 1993-1998, Austen *et al.* 1996, Scharf and Shugart 1998, Cuthbert *et al.* 2001, Weseloh *et al.* 2002, Morris *et al.* 2003, Hebert *et al.* 2008, Havelka and Weseloh in review, CWS unpublished 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 uncontaminated 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, point sources, re-suspension of sediments, and atmospheric inputs, as well as lesser-known ones such as underground leaks from landfill sites. There are also other, non-contaminant factors that regulate the stability of populations, e.g., habitat modification (in the Detroit River), food availability (Lake Superior), interspecific competition at breeding colonies

(Lake Ontario) and predation (Western Lake Erie). Many of these factors pose much more tangible threats to researchers' ability to collect eggs from these colonies in the future.

Management Implications

Data from the HGEMP suggest that, for the most part, contaminant levels in herring gulls are continuing to decline at a constant rate, though in 2007 there has been the noted slow down in the rate of decline (see above). However, even at current contaminant levels, more physiological abnormalities in herring gulls occur at Great Lakes sites than at cleaner, reference sites distant 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 these compounds to the Great Lakes. In short, although almost all contaminants are decreasing and many biological impacts have lessened, we do not yet know the full health implications of the subtle effects and of newly monitored contaminants.

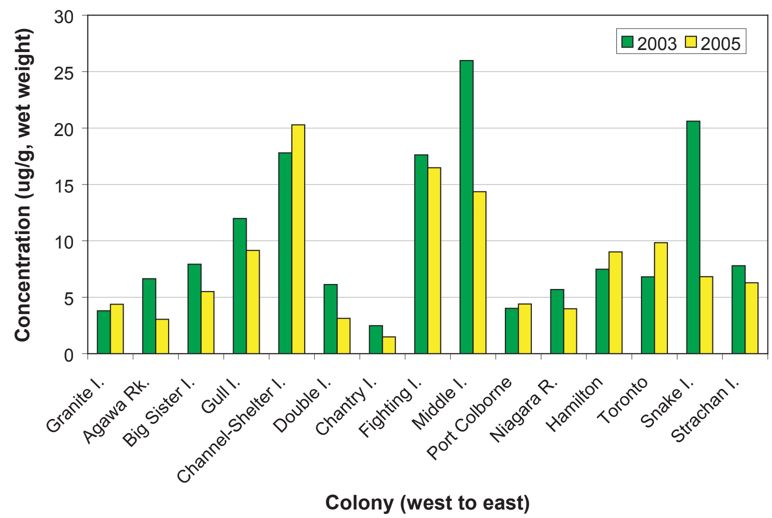

Figure 4. A comparison of PCB concentrations at all sites for 2003 and 2005.
Note the between-year differences as well as the variation among sites.
Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service.

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 activities. Research on improving and expanding the HGEMP is done on a more opportunistic, less predictable basis. A lake-by-lake intensive study of possible biological impacts to herring gulls is currently underway in the lower lakes. Recently, ecological tracers (stable isotopes and fatty acids) have been generated from archival eggs as part of the program, and they provide insights into how food webs in the Great Lakes ecosystem are changing. This information broadens the utility of the program from strictly examining contaminants to providing insights into ecosystem change. Ecological tracer data are also directly relevant to the interpretation of contaminant monitoring data.

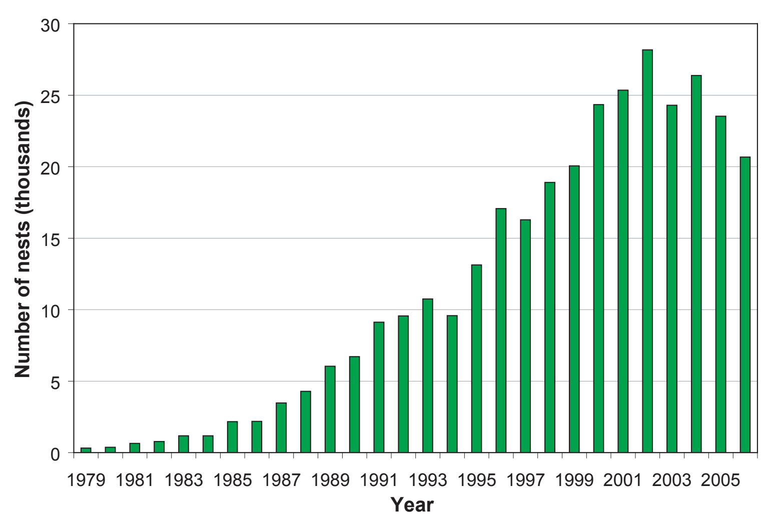

Figure 5. Double-crested Cormorant nests (breeding pairs) on Lake Ontario, 1979-2005.
Source: Environment Canada, Canadian Wildlife Service.

Comments from the author(s)

Much has been learned much about interpreting herring gull egg contaminants data from associated research studies. However, a significant portion of this work is conducted on an opportunistic basis when funds are available. Several research activities should be incorporated into routine monitoring, e.g., tracking of porphyria, vitamin A deficiencies, and evaluation of the avian immune system. Likewise, more research should focus on new areas, e.g., the impact of endocrine disrupting substances, factors regulating chemically induced genetic mutations and ecological tracers.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Zooplankton Populations

Indicator #116

Overall Assessment

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

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Unchanging
Rationale: Stable summer zooplankton community is dominated by large calanoid copepods.

Lake Michigan
Status: Not Assessed
Trend: Undetermined (changing)
Rationale: Total summer biomass has been declining since 2004 due to fewer cladocerans and cyclopoid copepods. Summer mean size of zooplankton is increasing as a result of increases in the large calanoid *Limnocalanus macrurus*.

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

Lake Erie
Status: Not Assessed
Trend: Undetermined
Rationale: Variable biomass and composition of summer crustacean zooplankton community in each basin. Most diverse zooplankton community in the Great Lakes. Very low biomass in Western basin in August 2001.

Lake Ontario
Status: Not Assessed
Trend: Undetermined (changing)
Rationale: Lowest percentage of calanoid copepods of all Great Lakes. Total summer biomass has declined since 2004 due to a decline in cyclopoid copepods.

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
- To infer changes in food-web dynamics due to changes in vertebrate or invertebrate predation, system productivity, the type and intensity of predation, and the energy transfer within a system

Ecosystem Objective

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

Planktivorous fish often feed size selectively, removing larger cladocerans and copepods. High densities of planktivores therefore can result in a reduction of the mean size of zooplankton in a community. A mean individual size of 0.8 mm (0.03 inches) has been suggested as "optimal" for zooplankton communities sampled with a 153 µm mesh net, indicating a balance between planktivorous and piscivorous fish (Mills *et al.* 1987). Declines in mean size of crustacean zooplankton between spring and late summer may indicate increased predation by young fish or the presence of a greater proportion of immature zooplankton. Interpretation of deviations from this average size objective, and the universality of this objective remain unclear at this time. In particular, questions regarding its applicability to systems impacted by predaceous cladocereans and dreissenids as well as planktivorous fish have been raised.

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

State of the Ecosystem

Summer biomass of crustacean zooplankton communities in the offshore waters of Lake Superior has remained at a relatively low but stable level since at least 1998 (Fig. 1). The plankton community is dominated by large calanoid copepods (*Leptodiaptomus sicilis* and *Limnocalanus macrurus*) that are characteristic of oligotrophic, cold water ecosystems. Biomass is generally higher in the nutrient enriched lower lakes with more annual variation produced by seasonal increases in cladocerans, primarily daphnids and bosminids. Since 2003 the biomass of cladocerans and cyclopoid copepods in Lake Huron has declined dramatically. Data from 2005 and 2006 suggest that a similar decline may now be occurring in Lake Michigan, although this has been offset somewhat by an increase in the biomass of *L. macrurus*. Cyclopoid abundance has also begun to decline in Lake Ontario. Mechanisms for these declines are not known at this time, but they may be related to changes in nutrient levels, phytoplankton composition, exotic species interactions, or fish predation pressure.

The proportion of calanoid copepods in Lake Superior has remained fairly stable at 70%, indicating oligotrophic conditions (Fig. 2). Summer zooplankton communities in Lake Michigan and Lake Huron have shown an increasing proportion of calanoid copepods in recent years, which ostensibly suggests an improved trophic state. In the case of Lake Michigan, this has been due both to an increase in *L. macrurus*, and a

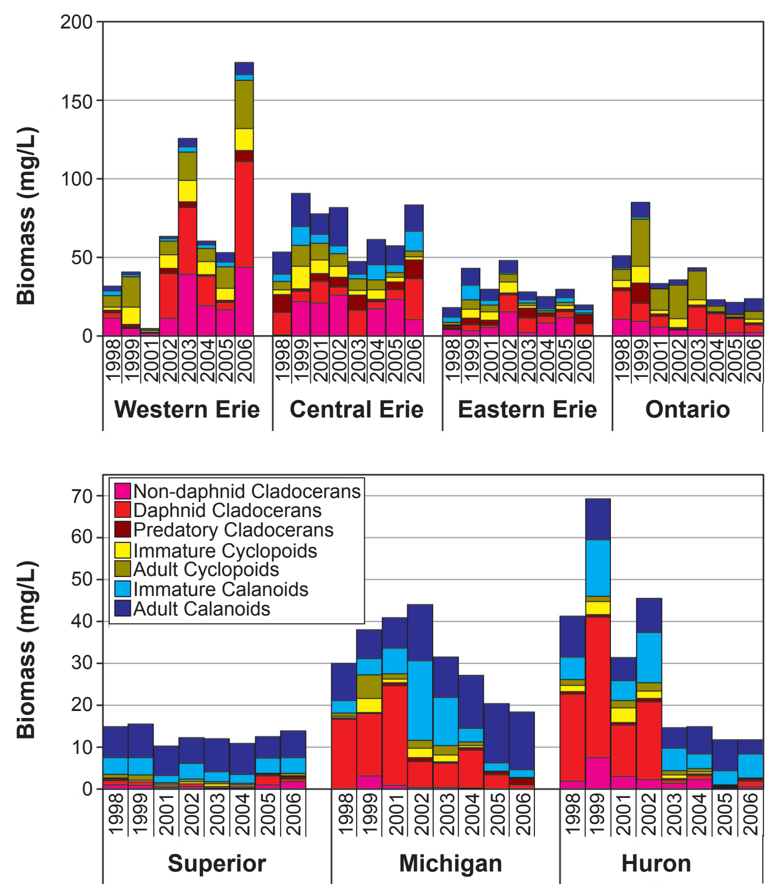

Figure 1. Average composition of crustacean zooplankton biomass at Great Lakes offshore stations sampled in August of each year. Samples were collected with 153 µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office.

decline in cladoceran populations. The increased proportion of calanoids in Lake Huron has resulted primarily from substantial declines in both cladoceran and cyclopoid copepod populations. Lake Ontario has the lowest proportion of calanoids, followed closely by the nutrient enriched western basin of Lake Erie. Values for the central and eastern basins of Lake Erie are at intermediate levels and exhibit considerable annual variation.

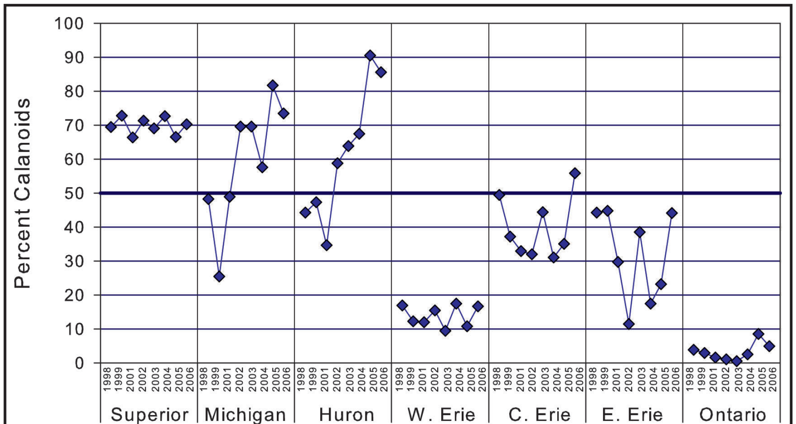

Figure 2. Average percentage of calanoid copepods (by abundance) in crustacean zooplankton communities from Great Lakes offshore stations sampled in August/September for 1998-2006 (excluding 2000). Samples were collected with 153 µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Line at 50% level is the suggested criterion for oligotrophic lakes.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office.

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/65 feet) 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 metres (65 feet). Comparisons in those two basins have shown a statistically significant increase in the ratio calanoids/(cladocerans + cyclopoids) between 1970 and 1983-1987, with this increase sustained throughout the 1990s. A similar increase was seen in the eastern basin, although some of the data used to calculate the ratio were generated from shallow tows and are therefore subject to doubt.

Mean length of crustacean zooplankton in the offshore waters of the Great Lakes is generally greater in the spring than during the summer (Fig. 3). In the spring, mean zooplankton size in all of the Great Lakes is near the suggested level of 0.8 mm (0.03 inches). Mean length in Lake Superior declines during the summer due to the production of immature copepods, but it is still above the criterion. Summer mean lengths in Lake Huron and Lake Michigan remain high and have begun to show increases in recent years, most likely due to the increased importance of *L. macrurus* noted above. In Lake Erie and Lake Ontario, the mean length of zooplankton declines considerably in the summer. Whether this decline is due to predation pressure or to the increased abundance of bosminids (0.4 mm/0.016 inches mean length) and immature cyclopoids (0.65 mm/0.025 inches mean length) is unknown.

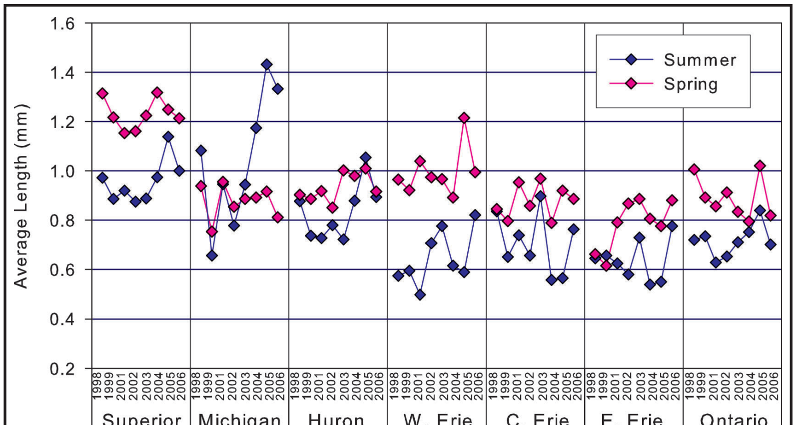

Figure 3. Average individual mean lengths of crustacean zooplankton in the Great Lakes in April/May and August/September for 1998-2006 (excluding 2000). Length estimates were generated from data collected with 153 µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Values are arithmetic averages of all sites sampled within each basin. Line at 0.8 mm is the suggested criterion for a balanced fish community.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office.

Historical data from the eastern basin of Lake Erie, from 1985 to 1998, indicate a fair amount of interannual variability in zooplankton mean length, with values from offshore sites ranging from about 0.5 to 0.85 mm (0.02 to 0.033 inches) (Fig. 4). As noted above, interpretation of these data is currently problematic.

Pressures

The zooplankton community might be expected to respond to changes in nutrient and phytoplankton concentrations in the lakes, although the potential magnitude of such "bottom up" effects is not well understood. The most immediate potential threat to the zooplankton communities of the Great Lakes is posed by non-native invasive species. The continued proliferation of dreissenid populations can be expected to impact zooplankton communities through the alteration of the structure and abundance of the phytoplankton community, upon which many zooplankton depend for food. Predation from the non-native cladocerans *Bythotrephes longimanus* and *Cercopagis pengoi* may also have an impact on zooplankton abundance and community composition. *Bythotrephes* has been in the Great Lakes for approximately twenty years and is thought to have had a major impact on zooplankton community structure (Barbiero and Tuchman 2004). *Cercopagis pengoi* was first noted in Lake Ontario in 1998 and has now spread to the other lakes, although in much lower densities. Continuing changes in predation pressure from planktivorous fish may also impact the system.

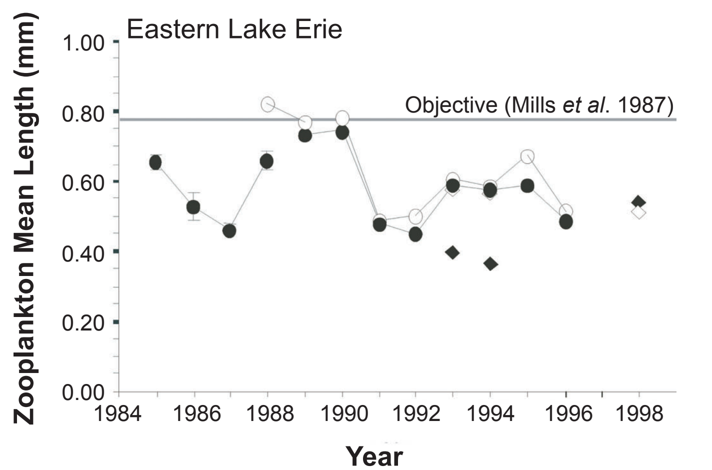

Figure 4. Trend in Jun27-Sep30 mean zooplankton length. New York Department of Environmental Conservation data (circles) collected with 153 µm mesh net, Department of Fisheries and Oceans (Canada) data (diamonds) converted from 64 µm to 153 µm mesh equivalent. Open symbols = offshore, solid symbols =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

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 pengoi* and the probability of future invasive non-native zooplankton and fish species.

Comments from the author(s)

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

The implementation of a long-term monitoring program on the Canadian side is also desirable to expand both the spatial, and in particular, 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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments

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Last Updated

State of the Great Lakes 2009

Atmospheric Deposition of Toxic Chemicals

Indicator #117

Overall Assessment

Status: **Mixed**

Trend: **Improving (for PCBs, banned organochlorine pesticides, dioxins and furans)/Unchanging or slightly improving (for PAHs and mercury).**

Rationale: **Different chemical groups have different trends over time. Levels in cities can be much higher than in rural areas.**

Levels of persistent bioaccumulative toxic (PBT) chemicals in air tend to be lower over Lake Superior and Lake Huron than over the other three Great Lakes (which are more impacted by human activity), but their surface area is larger, resulting in a greater importance of atmospheric inputs.

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

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

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To estimate the annual average loadings of 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
- 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, United States and Canada 1987) and the Binational Toxics Strategy (Environment Canada and U.S. Environmental Protection Agency 1997) 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 U.S.-Canada project has been in operation since 1990. Since that time, thousands of measurements of the concentrations of PCBs, pesticides, PAHs and trace metals have been made at these sites. Concentrations are measured in the atmospheric gas and particle phases and in precipitation. Spatial and temporal trends in these concentrations and atmospheric loadings to the Great Lakes can be examined. Data from other networks are used here to supplement the IADN data for mercury, dioxins and furans.

PCBs

Concentrations of gas-phase PCBs (ΣPCB) have generally decreased over time at the master stations (Fig. 1, Sun *et al.* 2007). ΣPCB is a suite of congeners that make up most of the PCB mass and that represent the full range of PCBs. Some increases are seen during the late 1990s for Lake Michigan and Lake 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 decreased again by 2002. It is assumed that PCB concentrations will continue to decrease slowly. PCBs in precipitation samples at the rural master stations are nearing levels of detection.

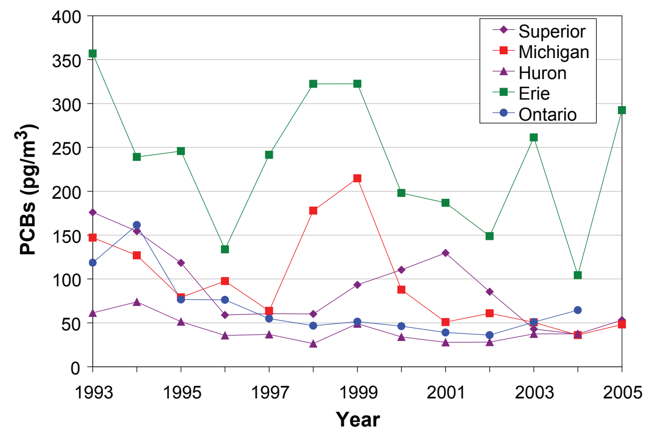

Figure 1. Annual Average Gas Phase Concentrations of Total PCBs (PCB Suite).
Source: Integrated Atmospheric Deposition Network (IADN) Steering Committee, unpublished, 2008.

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

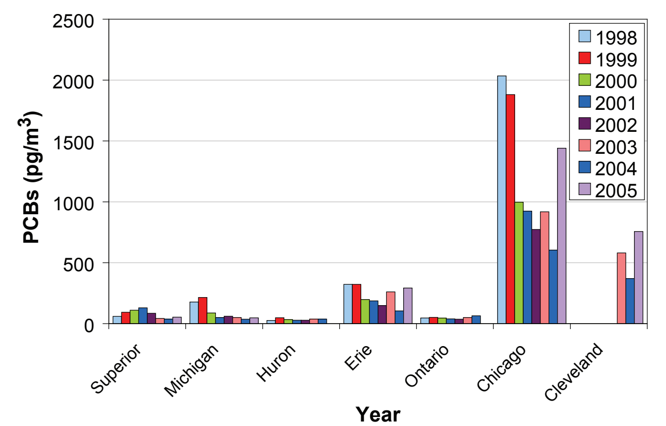

Figure 2. Gas Phase PCB concentrations for rural sites versus urban areas.
Source: IADN Steering Committee, unpublished, 2008.

Pesticides

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 (Sun *et al.* 2006a, Sun *et al.* 2006b). Concentrations of chlordane are about ten times higher at the urban stations than at the more remote master stations, most likely due to the use of chlordane as a termiticide in buildings. Dieldrin levels show a similar increase in urban locales. This pesticide was also used as a termiticide until 1987; after all other uses were banned in 1974. Current-use pesticide endosulfan shows mixed trends, with significant decreases at some sites in some phases, but no trends at other sites. Concentrations of endosulfan were generally higher in the summer, following application of this current-use pesticide (Sun *et al.* 2006b). An investigation of concentrations of atrazine, a current-use herbicide, at three Canadian IADN sites from 1996 to 2002 also yielded similar results with concentrations highest in the spring and early summer (Yao *et al.* 2007). Concentrations of atrazine also varied spatially with the highest concentrations occurring in Egbert and the lowest in Burnt Island. This is the pattern that would be expected if local usage is contributing to the levels observed at these sites (Yao *et al.* 2007).

PAHs

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

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

An example of a PAH is benzo(a)pyrene (BaP), which 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.

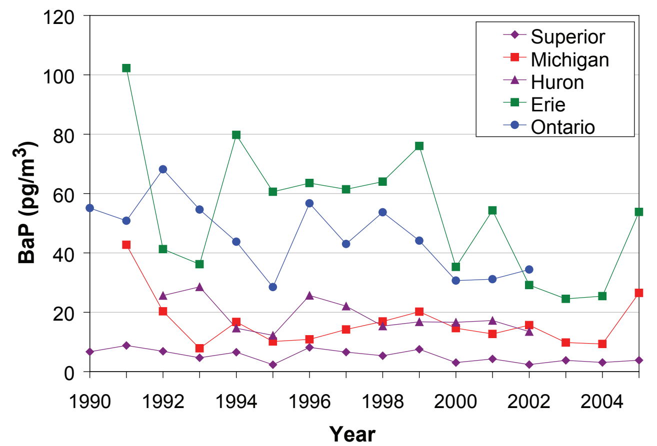

Figure 3. Annual Average Particulate Concentrations of Benzo(a)pyrene.
Source: IADN Steering Committee, unpublished, 2008.

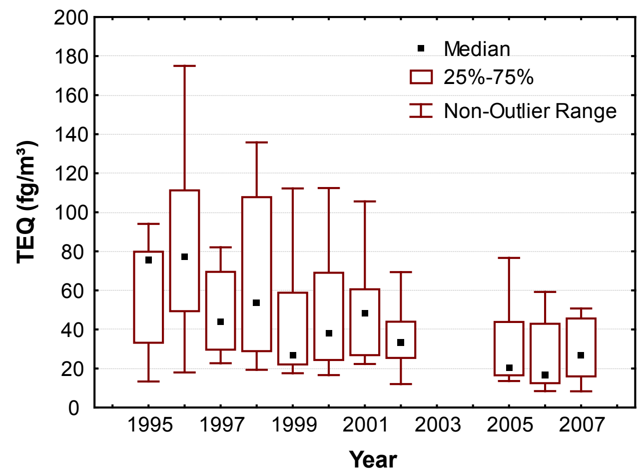

Figure 4. Concentrations of dioxins and furans expressed as TEQ (Toxic Equivalent) in fg/m³ in Hamilton, Ontario.
Source: Environment Canada National Air Pollution Surveillance (NAPS) network, unpublished, 2008.

Dioxins and Furans

Concentrations of dioxins and furans have decreased over time (Fig. 4) with the largest declines in areas with the highest historical concentrations (unpublished data, T. Dann, Environment Canada 2008).

Mercury

Data from the Canadian Atmospheric Mercury Measurement Network (CAMNet) for the IADN stations at Egbert, Point Petre, and Burnt Island show decreases in total gaseous mercury concentrations of 2.2%, 16.6%, and 5.1%, respectively from 1996 (1998 for Burnt Island) to 2005 (Temme *et al.* 2007). A large decrease in median concentrations from 2001 to 2002 dominates these overall trends for combined data at Egbert, Point Petre, and St. Anicet – all rural sites that are impacted by urban areas of Toronto or Montreal (Fig. 5).

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

PBDE

Total PBDE concentrations in the Great Lakes atmosphere during 2004-2006 were in the single pg/m^3 range for the rural master stations and in the 50 to 100 pg/m^3 range for the urban stations (Venier 2008). This is lower than total PCB levels, which are generally in the 10s to 100s of pg/m^3 range at the rural master stations. On a congener by congener basis, the atmospheric concentrations of BDE-47 and BDE-99 (but not of BDE-209) appear to be generally declining (Fig. 6). This reflects their historical usage with U.S. manufacturers having phased out production of penta-PBDE and octa-PBDEs in 2004, and deca-PBDE still being produced. However, three years worth of data is limited and future data will confirm whether levels of PBDEs increase or decrease in the air of the Great Lakes.

Loadings

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

A report on the atmospheric loadings of these compounds to the Great Lakes for data through 2005 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 by international agreements.

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

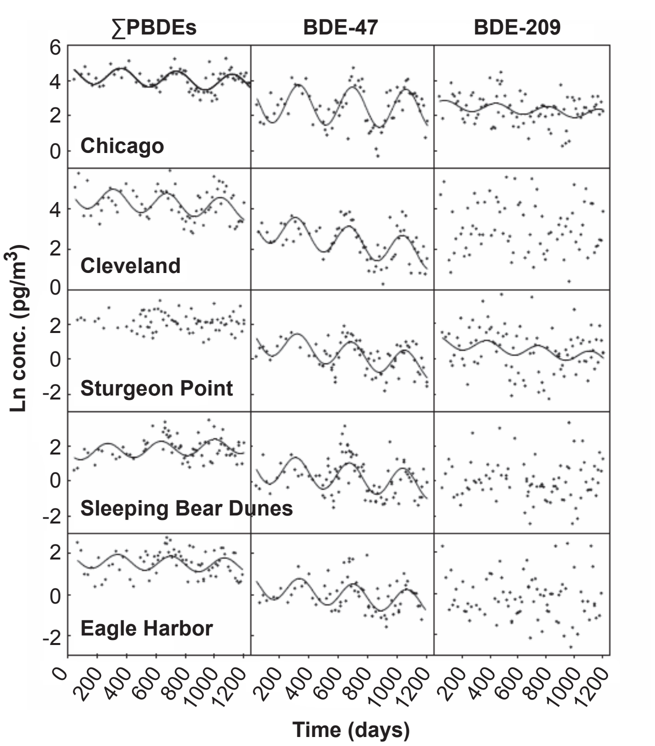

Figure 6. Temporal trends of total PBDEs, BDE-47, and BDE-209 (gas and particulate concentrations) in pg/m^3 at 5 IADN stations.
Source: Venier and Hites (2008).

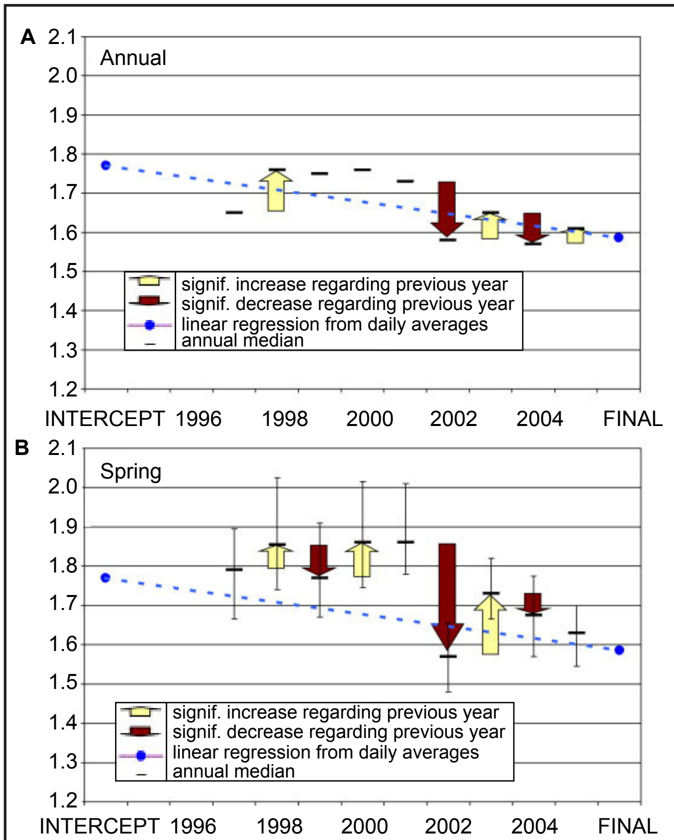

Figure 5. Median TGM concentrations and upper and lower quartiles (1997-2005): Comparison of significant year-by-year changes (arrows) to the overall linear regression (dotted line) obtained from daily averages after seasonal decomposition.
Source: Temme *et al.* (2007).

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

Management Implications

In terms of in-use agricultural chemicals, such as lindane, further restrictions on the use of these compounds may be warranted. Transport of lindane to the Great Lakes following planting of lindane-treated canola seeds in the Canadian prairies has been demonstrated through models (Ma *et al.* 2004b). On January 1, 2005, Canada withdrew registration of lindane for agricultural pest control. Agricultural uses of lindane in the United States will end in 2009 (Federal Register 2006).

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

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

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

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

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

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

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments

Author:

This report was prepared on behalf of the IADN Steering Committee by Todd Nettesheim, IADN Program Manager, U.S. Environmental Protection Agency, Great Lakes National Program Office (2008).

Contributors:

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Last Updated
State of the Great Lakes 2009

Toxic Chemical Concentrations in Offshore Waters

Indicator #118

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Concentrations of most organochlorine compounds are low and many are declining in the open waters of the Great Lakes, indicating progress in the reduction of persistent toxic substances. However, data are not available for all chemicals and changes to field and analytical methodology have made it difficult to discern temporal trends for some compounds.**

Lake-by-Lake Assessment

Lake Superior
Status: Fair
Trend: Undetermined
Rationale: Thirteen of a possible 21 organochlorine compounds were detected in Lake Superior in 2005 and their concentrations were generally very low. Some organochlorines are highest in Lake Superior due to the lake's susceptibility to atmospheric deposition. Mercury concentrations were very low offshore, with higher concentrations near Thunder Bay and Duluth. Polycyclic aromatic hydrocarbons (PAHs) were detectable throughout Lake Superior, albeit at extremely low concentrations.

Lake Michigan
Status: Fair
Trend: Undetermined
Rationale: Based on a limited assessment of six stations in 2006, 12 of a possible 21 organochlorine compounds were detected in Lake Michigan water samples. Total mercury concentrations in 2006 were low and were below the United States Environmental Protection Agency water quality criterion. PAHs were low, with some PAH compounds reflecting higher concentrations closer to urban sources. Atrazine concentrations were higher than the upper Great Lakes and within the range observed in Lakes Erie and Ontario.

Lake Huron
Status: Fair
Trend: Undetermined
Rationale: In 2007, 13 of a possible 21 organochlorine compounds were detected in Lake Huron. Of these, 11 were commonly found, including hexachlorocyclohexane (α-HCH), lindane, dieldrin, and γ-chlordane. The concentrations were generally low, reflecting historical or diffuse sources. Mercury and PAH concentrations in Lake Huron and Georgian Bay were very low.

Lake Erie

Status: Mixed

Trend: Undetermined

Rationale: In 2006, 14 of a possible 21 organochlorine compounds were detected in Lake Erie. Concentrations of α-chlordane exceeded the strictest water quality guideline in the Great Lakes basin (NYSDEC guideline) at one station. Concentrations of most compounds were highest in the shallow western basin and much lower in the central and eastern basins. Mercury concentrations in the western basin were the highest observed in the Great Lakes, but mercury concentrations in the eastern basin were as low as the other lakes. PAH concentrations and distributions reflect urban source areas and upstream sources within the St. Clair River – Detroit River corridor.

Lake Ontario

Status: Mixed

Trend: Undetermined

Rationale: In 2006, 13 of a possible 21 organochlorine compounds were detected in Lake Ontario. Hexachlorobenzene, dieldrin, lindane, α-HCH and DDT compounds were routinely found at levels higher than elsewhere in the basin. Total PCBs were also higher in Lake Ontario compared to the other Great Lakes. Mercury concentrations in Lake Ontario were low in the offshore areas and higher in the nearshore, but only samples taken from Hamilton Harbour exceeded the USEPA water quality criteria. PAH distribution and concentrations reflected urban source areas.

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
- 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, please refer to Marvin *et al*. (2004), Kannan *et al*. (2006), and *Trends in Great Lakes Sediments and Surface Waters* in Chapter 8 of the Great Lakes Binational Toxics Strategy 2006 progress report.

Since 1986, Environment Canada has conducted toxic contaminant monitoring in the shared waters of the Great Lakes. Starting in 2004, Environment Canada has developed and employed new measurement techniques and invested in an ultra-clean laboratory in order to more accurately measure these trace concentrations of pollutants in the surface waters of the Great Lakes. The data presented here are the results of this new methodology. Data are available for all of the shared waters, as well as a limited survey of Lake Michigan (six stations) in 2006. The analyte list includes chlorobenzenes, organochlorines, PCBs (as congeners), PAHs, trace metals including mercury, as well as a limited number of in-use pesticides.

Recent (2005 – 2007) water quality testing has found that only a small number of compounds are found ubiquitously in the basin at concentrations above laboratory detection limits. This category comprises a small number of chlorinated benzenes (including pentachlorobenzene (PECB) and hexachlorobenzene (HCB)), organochlorine compounds (γ-HCH, dieldrin and heptachlor epoxide), PAHs (fluoranthene) and currently-used pesticides (atrazine and metolachlor). Total PCBs are also routinely found, although at some stations the levels are not significantly above field and laboratory-blank levels.

Surveys conducted between 1992 and 2000 (Marvin *et al.* 2004) and during 2005-2007 (Environment Canada Great Lakes Surveillance Program, unpublished data) have showed that concentrations of most organochlorine compounds are below the most stringent water quality guidelines. One exception is that the NYSDEC guideline for a-chlordane was exceeded at one nearshore station in Lake Ontario and one station in the western basin of Lake Erie in 2006. In some cases (e.g., dieldrin, total PCBs), the laboratory detection limit is not yet sufficiently low to permit a comparison with the most stringent water quality guidelines in the basin.

Many organic compounds (such as PECB, HCB, total PCBs and DDT) show spatial patterns that indicate higher concentrations near historical, localized sources. Concentrations in offshore waters are lower than nearshore, and concentrations in the upper Great Lakes are lower than the Lakes Erie and Ontario.

Exceptions to this pattern do exist. For example, compounds that are primarily distributed by atmospheric deposition rather than point sources, such as lindane and α-HCH, are found at higher concentrations in the north. In these cases, concentrations are highest in Lake Superior and are lower in the other lakes. The recent distribution of dissolved dieldrin in surface waters (Fig. 1) shows an interesting pattern of atmospheric redistribution combined with proximity to historical source areas.

Currently-emitted compounds, such as PAHs, which are released during fossil fuel combustion, also show spatial patterns that are indicative of sources. Concentrations of PAHs are therefore higher in the lower lakes, where usage is greater. The lighter PAHs are also ubiquitous in the upper Great Lakes, but their concentrations are much lower. Concentrations of the heavier PAHs, which are not as subject to atmospheric transport due to their partitioning to particles, are highest in the lower Great Lakes, where human populations are greater.

Mercury concentrations (Fig. 2) overall are very low, and concentrations in the open lake areas are currently below the U.S. EPA Great Lakes Initiative (GLI) water quality criterion of 1.3 ng/L (USEPA 2006). However, higher concentrations are observed in the western basin of Lake Erie in particular, and in some harbors and major urban areas as well (e.g., Toledo, Hamilton, Duluth, Cleveland, Rochester, Chicago). Some samples near these urban areas exceed the GLI water quality criterion for the protection of wildlife.

Certain parameters have shown a marked decline over time. Concentrations of pentachlorobenzene (PECB) in Lake Ontario have fallen by 71% since 1993, although the rate of decline appears to have slowed in recent years. Similarly, lindane (γ-HCH) and α-HCH concentrations have declined in Lake Ontario by 68%

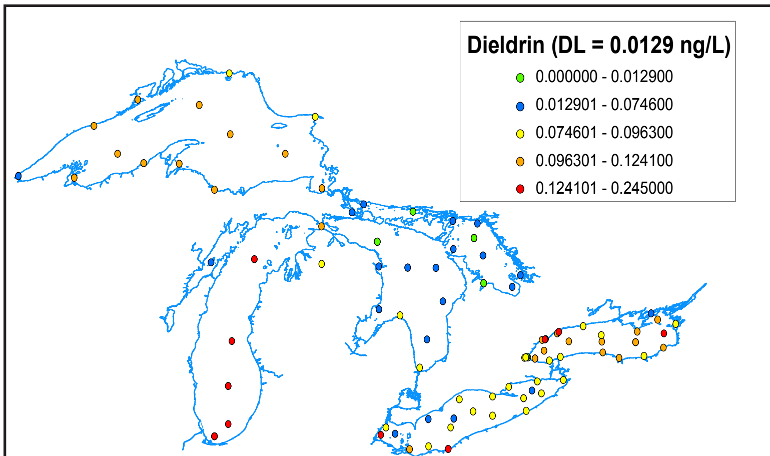

Figure 1. Great Lakes 2005-2007 Spring, Surface Water Concentrations of Dieldrin (ng/L).
Source: Environment Canada's Great Lakes Surveillance Program, Burlington, Ontario. Data for Lakes Superior and Ontario are from 2005, Lakes Michigan and Erie are from 2006, and Lake Huron and Georgian Bay are 2007.

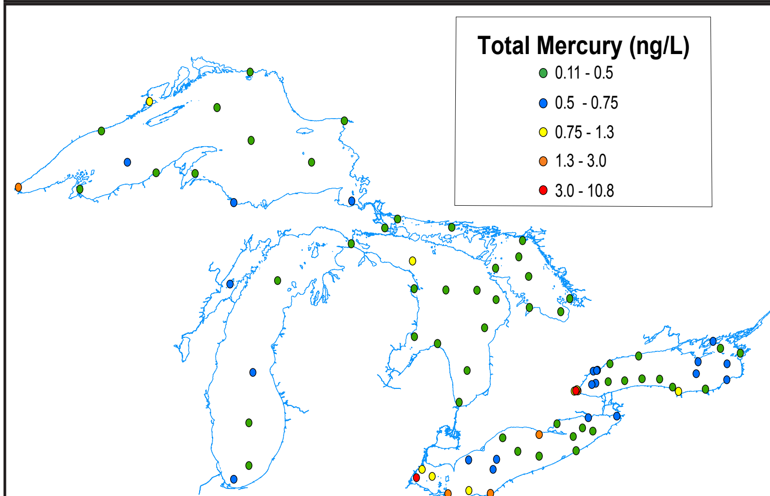

Figure 2. Great Lakes 2005-2007 Spring, Surface Water Concentrations of Total Mercury (ng/L).
Source: Environment Canada's Great Lakes Surveillance Program, Burlington, Ontario. Data for Lake Superior are from 2005, Lakes Michigan, Erie and Ontario are from 2006, and Lake Huron and Georgian Bay are 2007.

and 90%, respectively, since 1992. Reductions are largely due to the ban of these compounds and the subsequent control of point sources. The rates of decline appear to be slowing, however, as residual levels are persistent in the environment. For example, the rate of decrease in α-HCH in Lake Ontario from 1992 to 1998 was 0.12 ng/L per year, but the rate from 1998 to 2006 has slowed to 0.04 ng/L per year.

Concentrations of HCB, whose use as a fungicide was discontinued in 1976, but which can be released as a by-product from the manufacture of a variety of organic chemicals and from the incineration or processing of chlorinated solvents and pesticides, have not changed significantly between 1998 and 2006 in Lake Ontario or in Lake Erie. Similarly, no significant change in the concentration of δ-BHC is observed in the lakes since 1992.

In contrast, the concentrations of currently-used pesticides atrazine and metolachlor have increased by 57% and 31%, respectively, between 1998 and 2006 in Lake Ontario. Detectable concentrations of these two pesticides are found ubiquitously in all of the lakes, with higher concentrations reflecting source areas primarily in the watersheds of Lakes Ontario, Erie and Michigan.

The best available information for the determination of longer-term temporal trends is bottom sediment quality. This information indicates that concentrations of total PCBs and mercury, among other parameters, have declined markedly over the past 30 years. The concentration of total PCBs in Lake Erie surficial bottom sediments has fallen from a lakewide average concentration of 136 ng/g in 1971 to 43 ng/g in 1997 (Painter *et al*., 2001), a three-fold decline. Concentrations of mercury in bottom sediments have decreased in all of the Great Lakes since the peak (approximate 1968 – 1975) period with the exception of Lake Superior, where levels approach geologic norms. Reductions in mercury contamination in sediments across the basin, estimated by comparisons of recent and historical surveys, range from 24% for Lake Ontario to 60% for western Lake Erie and 80% for Lake Huron (Marvin *et al*., 2004b).

Management Implications

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

Efforts need to be maintained to identify and track the remaining sources and explore opportunities to accelerate their elimination (e.g., via the Great Lakes Binational Toxics Strategy). Targeted monitoring to identify and track down local sources of LaMP critical pollutants is being conducted in Great Lakes watersheds. However, an expansion of the track-down program should be considered to include other priority chemicals whose distributions suggest localized influences.

Compounds that are included in Canada's Chemical Management Plan and the BTS surveillance for compounds of emerging concern, as well as other chemicals that act as endocrine disruptors, in-use pesticides and pharmaceuticals, are emerging issues. Surveillance and monitoring for parameters of emerging concern is being prioritized by discussions with risk assessors and managers, in order to first address substances that are most likely to be persistent, bioaccumulative, and/or inherently toxic in the aquatic environment and is providing an early warning system to help anticipate possible future toxic substance problems.

Comments from the author(s)

Data are for Lake Superior (2005), Lake Huron and Georgian Bay (2007), Lake Erie (2006) and Lake Ontario (2005 and 2006) as well as limited survey data for Lake Michigan (2006).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes: Comparable data have not been generated by the US during the time frame of the data presented here (2005-2007). Data presented here have not been compared with older US data.						

Acknowledgments
Author:
Alice Dove, Environment Canada, Water Quality Monitoring and Surveillance, Burlington, ON (2008)

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Last Updated
State of the Great Lakes 2009

Concentrations of Contaminants in Sediment Cores

Indicator #119

Overall Assessment

Status: **Mixed**
Trend: **Improving/Undetermined**
Rationale: **There have been significant declines over the past several decades in concentrations of many contaminants including PCBs, DDT, lead, and mercury due to successful management actions. Current focus is on the determination of the occurrence, distribution and fate of modern societal contaminants including brominated flame retardants and perfluoroalkylated substances, ingredients in surfactants.**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

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

Ecosystem Objective

The Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human health, animal, or aquatic life (Great Lakes Water Quality Agreement (GLWQA), Article III(d), United States and Canada 1987). 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

Sediments in the Great Lakes generally represent a primary sink for contaminants, and can act as a source through resuspension and subsequent redistribution within the individual lakes. However, burial in sediments also represents a primary mechanism by which contaminants are sequestered and prevented from re-entering the water column.

Bottom sediment contaminant surveys conducted in the Great Lakes from 1968 - 1974 and from 1997 - 2002 provide information on the spatial distribution of contaminants, the impacts of local historical sources and, in concert with sediment cores, the response to management initiatives. Comparisons of surficial sediment contaminant concentrations with sub-surface maximum concentrations indicate that contaminant concentrations have generally decreased by more than 35%, and, in some cases, by as much as 80%. Table 1 shows percentage reductions in

Parameter	Ontario %Reduction	Erie %Reduction	St. Clair %Reduction	Huron %Reduction	Superior %Reduction
Mercury	73	37	89	82	0
PCBs	37	40	49	45	15
Dioxins	70	NA	NA	NA	NA
HCB	38	72	49	NA	NA
Total DDT	60	42	78	93	NA
Lead	45	50	74	43	10

Table 1. Estimated percentage declines in sediment contamination in the Great Lakes based on comparison of surface sediment concentrations with maximum concentrations at depth in sediment cores.
Source: Environment Canada.

contaminant concentrations (surface vs. sub-surface) in Lakes Ontario, Erie, Huron, Superior and St. Clair from available sediment core data.

Spatial distributions in mercury contamination generally represent those of other toxics, both other metals and organics such as polychlorinated biphenyls (PCBs), as accumulation of a broad range of contaminants on a lake-by-lake basis can be the result of common sources, e.g., chlor-alkali production. The highest concentrations of mercury in sediments of Lakes Michigan, St. Clair, Erie and Ontario are observed in offshore depositional areas characterized by fine-grained sediments (Fig. 1). Contaminant concentrations are generally correlated with particle size; hence the distribution of mercury is not only a function of loadings and proximity to sources, but of the influence of substrate type and bathymetry as well. Mercury contamination is found generally quite low in Lakes Huron, Michigan and Superior and higher in Lakes St. Clair, Ontario and the western basin of Lake Erie. There is an apparent spatial distribution in contamination in Lake Erie with decreasing concentrations from the western basin to the eastern basin, and from the southern area to the northern area of the central basin. The spatial pattern in Lake Erie is influenced by industrial activities in the watersheds of major tributaries, including the Detroit River, and areas along the southern shoreline. Sources and loadings of mercury to Lake Huron appear to have been reduced to the point that no apparent spatial pattern exists. Elevated concentrations of mercury are found in the central and east-central areas of Lake St. Clair, the western basin of Lake Erie, and the three major depositional basins of Lake Ontario. The current degree of contamination in these areas is substantially lower than peak levels that occurred in the mid – 1950s through the early 1970s. However, the similarity in spatial patterns between recent and historical surveys indicates significant sources within the individual lake basins continue to influence contaminant distributions over large areas. Areas of the major connecting channels including the Niagara, lower Detroit and upper St. Clair Rivers are all associated with historical mercury cell chlor-alkali production; these areas were also intensively industrialized and were primary sources of a variety of persistent toxics to the open lakes, including PCBs. Localized areas of highly contaminated sediment, and/or hazardous waste sites associated with these industrial historical sources, may continue to act as sources of these contaminants and influence their spatial distributions. Conversely, these local sources may no longer be predominant, and the spatial patterns observed in our most recent surveys may reflect resuspension, intra-lake mixing and deposition of existing sediment inventories. In this case, further declines would be expected as these contaminants are ultimately deposited and buried in the sedimentary record.

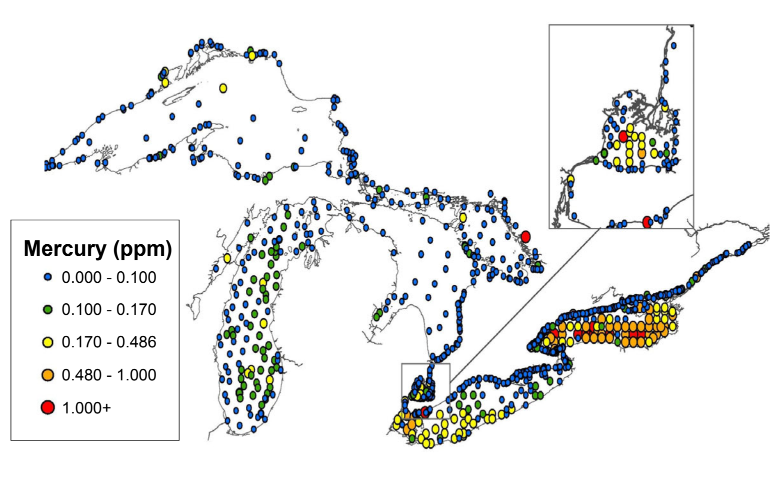

Figure 1. Spatial distribution of mercury contamination in surface sediments in open lake areas and tributaries of the Great Lakes.
Sources: Environment Canada and USEPA.

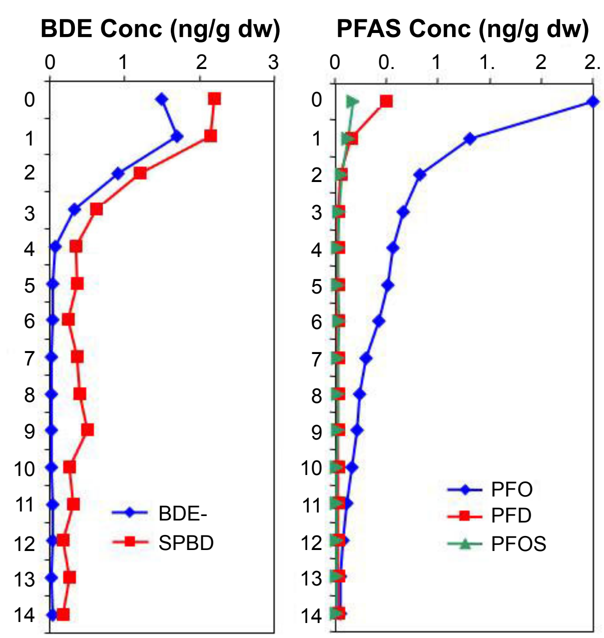

Figure 2. Core profiles of perfluoroalkyl subtances (PFAS) and brominated diphenyl ethers (BDEs) is sediment cores from the central (Mississauga Basin) basin of Lake Ontario.
Sources: Environment Canada and Ontario Ministry of the Environment.

Surficial sediment concentrations can also be assessed against guideline values established for the protection of aquatic biota, e.g., the Canadian Sediment Quality Guidelines Probable Effect Level (CCME, 1999). These guidelines can be applied as screening tools in the assessment of potential risk, and for the determination of relative sediment quality concerns. For metals and

PCBs, Probable Effect Level (PEL) guideline exceedances were frequent in Lake Ontario for lead, cadmium and zinc. Guideline exceedances were rare in all of the other lakes, with the exception of lead in Lake Michigan where the PEL (91.3 µg/g) was exceeded at over half of the sites. There were no PEL (277 ng/g total PCBs) guideline exceedances for PCBs in any of the Great Lakes sediments.

The presence of new persistent toxics represents an emerging threat to the health of the Great Lakes ecosystem. These compounds include perfluoroalklated substances (PFAs) and brominated flame retardants (BFRs), the latter of which are heavily used globally in the manufacturing of a wide range of consumer products and building materials. The BFRs have been found to be bioaccumulating in Great Lakes fish and in breast milk of North American women. Assessment of the occurrence and fate of these new compounds has recently been incorporated into bottom sediment monitoring programs. While government initiatives for reducing indiscriminant urban and industrial discharges of legacy compounds like PCBs have resulted in decreasing trends, the new and emerging compounds have not shown corresponding trends. While end-of-pipe discharges may not be responsible for ongoing contamination, modern urban/industrial centres can act as diffuse sources of current inputs. Sediment core profiles of brominated diphenyl ethers (BDEs) and PFAs in Lake Ontario suggest that accumulation of these chemicals has only recently peaked, or continues to increase (Fig. 2). The Lake Ontario BDE profile indicates a leveling off of accumulation in the past decade, presumably as a result of voluntary cessation of production of these compounds in North America. However, the deca-substituted BDE 209 is the predominant congener in sediment, and is still currently produced. Despite these trends, maximum concentrations of many BFRs and PFAs remain well below maximum concentrations of contaminants such as DDT and PCBs observed in past decades.

Pressures

Management efforts to control inputs of historical contaminants have resulted in decreasing contaminant concentrations in the Great Lakes open-water sediments for the standard list of chemicals. However, additional chemicals such as brominated flame retardants and current-use pesticides may represent emerging issues and potential future stressors to the ecosystem. These results corroborate observations made globally, which indicate that large urban centers act as diffuse sources of chemicals that are heavily used to support our modern societal lifestyle.

Management Implications

The Great Lakes Binational Toxics Strategy needs to be maintained to identify and track the remaining sources of legacy contaminants and to explore opportunities to accelerate their elimination. In addition, targeted monitoring to identify and track down local sources of pollution should be considered for those chemicals whose distribution in the ambient environment suggests local or sub-regional sources. Ongoing monitoring programs in the Great Lakes connecting channels (e.g., Detroit River, Niagara River) provide valuable information on the success of binational management actions to reduce or eliminate discharges of toxic substances to the Great Lakes. The Great Lakes Binational Toxics Strategy also needs to be proactive in addressing issues related to the distribution and fate of chemicals heavily used by our modern urban/industrial society.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

Acknowledgments
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Last Updated
State of the Great Lakes 2009

Contaminants in Whole Fish

Indicator #121

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Rationale: **Over time, concentrations of historically regulated contaminants have generally declined in most monitored fish species. The concentrations of other contaminants, currently regulated and unregulated, vary in selected fish communities. The changes are often lake-specific and relate both to the characteristics of the substances involved and the biological composition of the fish community.**

Lake-by-Lake Assessment

Polychlorinated biphenyls (PCB) and dichlorodiphenyltrichloroethane (DDT) levels are measured in lake trout and walleye while only smelt samples have recent mercury trend data available.

Lake Superior

Status: Fair
Trend: Improving
Rationale: Concentrations of ΣPCBs show little change, ΣDDT shows fluctuating concentrations, while mercury concentrations continue to decline. ΣPCB concentrations remain above GLWQA criteria while ΣDDT and mercury remain below. Contaminants in Lake Superior are typically atmospherically-derived. The dynamics of Lake Superior allow contaminants to be retained much longer than in any other Great Lake.

Lake Michigan

Status: Fair
Trend: Improving
Rationale: Concentrations of ΣPCBs and ΣDDT are declining. ΣPCB levels remain above GLWQA criteria and ΣDDT levels remain below. Food web changes are critical to Lake Michigan contaminant concentrations. Aquatic invasive species such as Asian carp are also of major concern to Lake Michigan due to the connection of Chicago Sanitary and Ship Canal and the danger the carp pose to the food web.

Lake Huron

Status: Fair
Trend: Improving
Rationale: Both ΣPCBs and DDT show general declines in concentrations while mercury displays a flux. ΣPCB concentrations remain above GLWQA criteria while ΣDDT and mercury remain below. Contaminant loading to Saginaw Bay continues to be reflected in fish tissue contaminant levels.

Lake Erie

Status: Fair
Trend: Improving
Rationale: ΣPCBs and DDT concentrations show a pattern of annual increases linked to changes in invasive species populations, such as zebra and quagga mussels. Aquatic invasive species are of major concern to Lake Erie. Although mercury concentrations are the highest ever recorded in Lake Erie, mercury and ΣDDT remain below GLWQA criteria while ΣPCB concentrations remain above.

Lake Ontario

Status: Fair

Trend: Improving

Rationale: Both ΣPCBs and DDT concentrations show a pattern of decline while mercury concentrations show little change. ΣPCB concentrations remain above GLWQA criteria while ΣDDT and mercury remain below. Historic point sources of mirex and OCS have resulted in higher concentrations in Lake Ontario than any other Great Lake. Contaminants of emerging concern, such as polybrominated diphenylethers (PBDEs) and perfluorooctane sulfonate (PFOS), continue to raise alarm in Lake Ontario.

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
- 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 12 (Persistent Toxic Substances).

State of the Ecosystem

Background

Long-term (greater than 25 years), basin-wide monitoring programs that measure whole body concentrations of contaminants in top predator fish (lake trout (*Salvelinus namaycush*) and/or walleye (*Sander vitreus*)) and in forage fish (smelt) are conducted by the U.S. Environmental Protection Agency (U.S. EPA) Great Lakes National Program Office (GLNPO) through the Great Lakes Fish Monitoring Program, and Environment Canada, through the Fish Contaminants Surveillance Program, to determine the effects of contaminant concentrations on wildlife and to monitor trends. Environment Canada reports annually on contaminant burdens in similarly aged lake trout (4+ through 6+ year range), walleye (Lake Erie), and in smelt. GLNPO annually monitors contaminant burdens in similarly sized lake trout (600-700 mm total length) and walleye (Lake Erie, 400-500 mm total length) from alternating locations by year in each lake. Details of the program can be found at, http://www.epa.gov/glnpo/glindicators/fish.html. Differences between the United States and Canadian programs, including collection site differences and varying species collections, inhibit the direct comparison of results from the two programs.

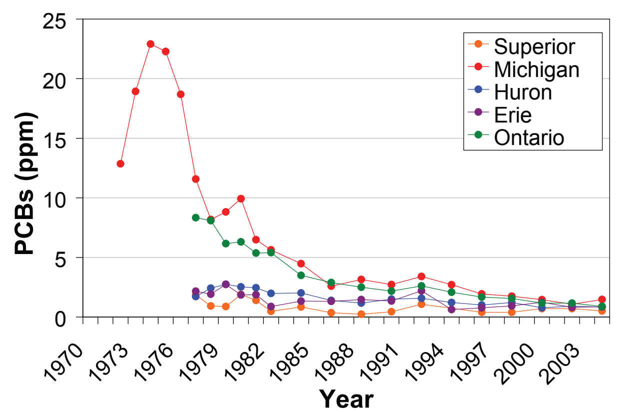

Figure 1. Total PCB in Even Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1972 - 2003 µg/g wet weight +/- 95% C.I., composite samples.
Lake Trout = 600-700 mm size range. *Fish collected between 1972 and 1982 were collected at even year sites only. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

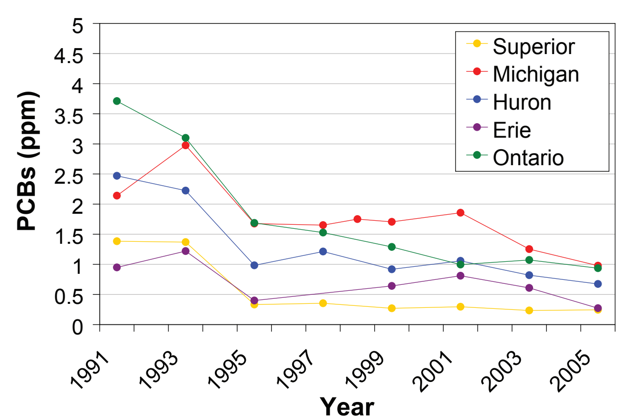

Figure 2. Total PCBs in Odd Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1991 – 2005 µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

In 2006, Environment Canada assumed responsibilities for the Fish Contaminant Surveillance Program from the Department of Fisheries and Oceans Canada (DFO). All data prior to 2006, in this indicator report were produced by DFO.

Also in 2006, the Great Lakes Fish Monitoring Program was granted to a new principal investigator. Data from 2004 and beyond was provided by Clarkson University.

Chemical Concentrations in Whole Great Lakes Fish

Since the late 1970s, concentrations of historically regulated contaminants such as PCBs, DDT and mercury have generally declined in most monitored fish species. The concentration of other contaminants, currently regulated and unregulated, has demonstrated either slowing declines or, in some cases, increases in selected fish communities. The changes are often lake-specific and relate both to the characteristics of the substances involved and the biological composition of the fish community.

The GLWQA, first signed in 1972, renewed in 1978, and amended in 1987, expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem. When applicable, contaminant concentrations are compared to GLWQA criteria.

Total PCBs

Total PCB concentrations in Great Lakes top predator fish have continuously declined since their phase-out in the 1970s (Figs. 1-4). However, rapid declines are no longer observed and concentrations in fish remain above the U.S. EPA wildlife protection value of 0.16 ppm and the GLWQA criteria of 0.1 ppm. Concentrations remain high in top predator fish due to the continued release of uncontrolled sources and their persistent and bioaccumulative nature.

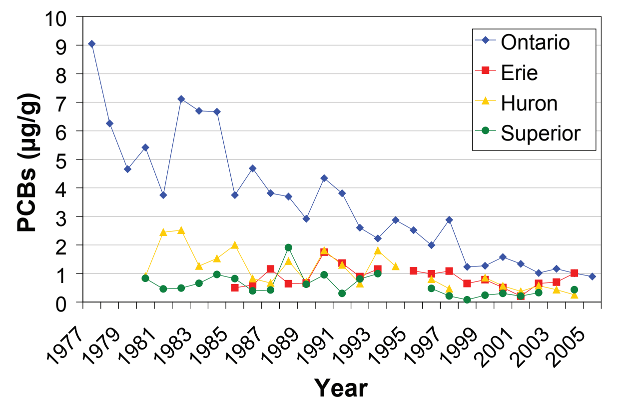

Figure 3. Total PCBs in 4 to 6 year old individual whole Environment Canada Lake Trout, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

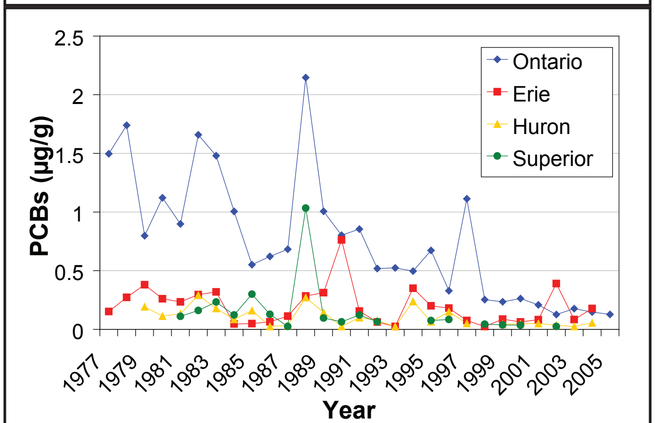

Figure 4. Total PCBs in composite Environment Canada rainbow smelt, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

Total DDT

Total DDT concentrations in Great Lakes top predator fish have continuously declined since the chemical was banned in 1972. However, large declines are no longer observed. Rather, very small annual percent declines are seen, indicating near steady state conditions (Figs. 5-8). It is important to note that the concentrations of this contaminant remain below the GLWQA criteria of one ppm. There is no U.S. EPA wildlife protection value for total DDT because the PCB value is more protective.

Mercury

Concentrations of mercury are similar across all fish in all Great Lakes. It is assumed that concentrations of mercury in top predator fish are atmospherically driven. It is important to note that current concentrations in top predator fish sampled by GLNPO in all lakes remain above the GLWQA criteria of 0.5 ppm (Fig. 9) as do the majority of lake trout sampled by Environment Canada (Fig. 10). It is also important to note that smelt sampled by Environment Canada have never been observed to be above the GLWQA criteria (Fig. 11).

Total Chlordane

Concentrations of total chlordane have consistently declined in whole top predator fish since the U.S. EPA banned it in 1988 (Figs. 12-13). Total chlordane is composed of cis- and trans-chlordane, cis- and trans-nonachlor, and oxychlordane, with trans-nonachlor being the most prevalent of the compounds. While trans-nonachlor was one of the five components of the technical chlordane mixture, it is the least metabolized and predominates within the food web (Carlson and Swackhamer 2006).

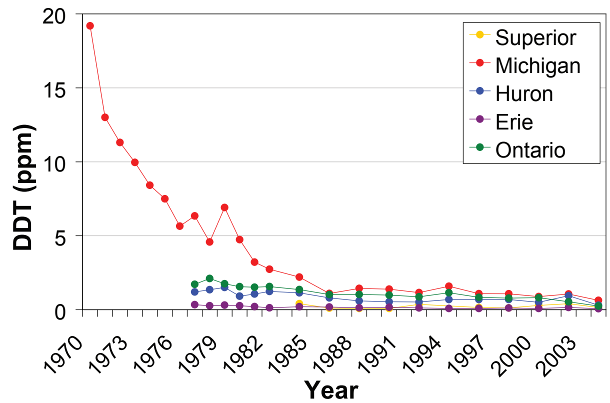

Figure 5. Total DDT in Even Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1972 - 2003. µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. *Fish collected between 1972 and 1982 were collected at even year sites only. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

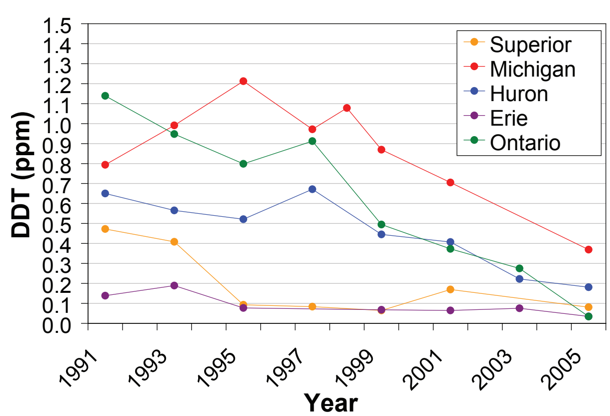

Figure 6. Total DDT in Odd Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1991 - 2005. µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency

the highest in Lake Superior due to its longer retention time, cold temperatures, and slow sedimentation rate. It is assumed that concentrations of toxaphene in top predator fish are atmospherically driven (Hites 2006).

PBDEs

The more toxic penta and octa formulations of PBDE were discontinued in 2004 in the United States while the less toxic and more stable deca formulation continued to be produced. Both U.S. EPA and Environment Canada analyze for PBDEs in whole top predator fish. Retrospective analyses of archived samples demonstrated an increase in concentrations of PBDEs and continued through the early 2000s. More recent samples display a decline in total PBDEs (Fig. 24). Ongoing research

Mirex

Concentrations of mirex are highest in Lake Ontario top predator fish and smelt due to its continued release from uncontrolled historic sources near the Niagara River (Figs. 16-19).

Dieldrin

Concentrations of dieldrin in lake trout appear to be declining in all Great Lakes and are lowest in Lake Superior and highest in Lake Michigan (Figs. 20-23). Concentrations in Lake Erie walleye were lower than those in lake trout from the other Great Lakes. Aldrin is readily converted to dieldrin in the environment. For this reason, these two closely related compounds (aldrin and dieldrin) are considered together by regulatory bodies.

Toxaphene

Decreases in toxaphene concentrations have been observed throughout the Great Lakes in all media following its ban in the mid-1980s. However, concentrations have remained

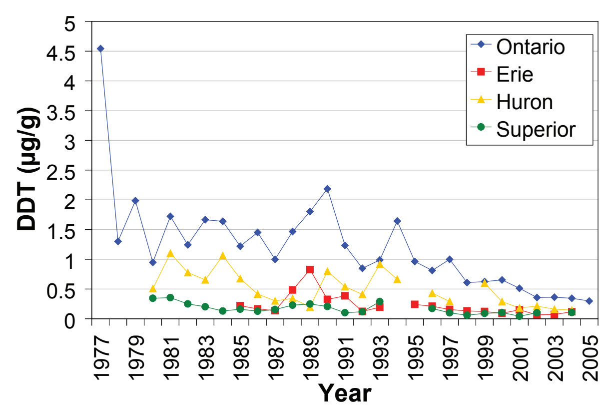

Figure 7. Total DDT in 4 to 6 year old individual whole Environment Canada Lake Trout, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

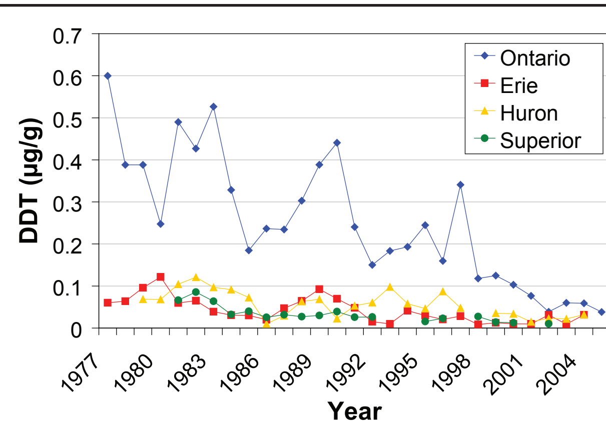

Figure 8. Total DDT in composite Environment Canada rainbow smelt, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

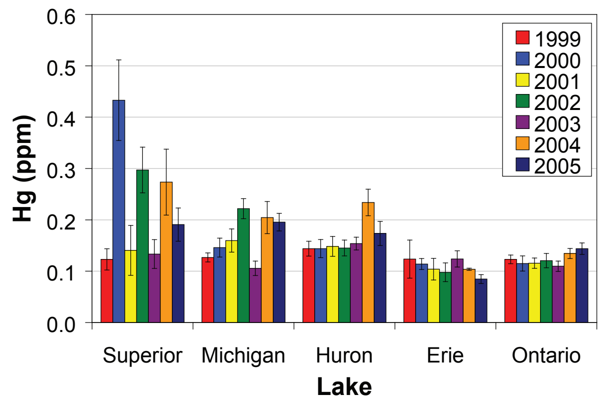

Figure 9. Mercury in whole EPA Lake Trout composites (Walleye in Lake Erie), 1999 – 2005, µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

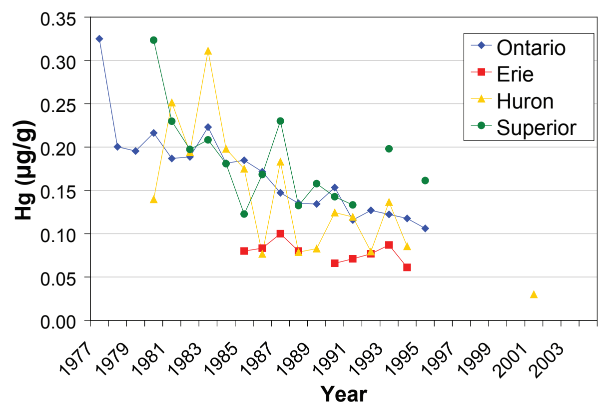

Figure 10. Mercury in 4 to 6 year old individual whole Environment Canada Lake Trout, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

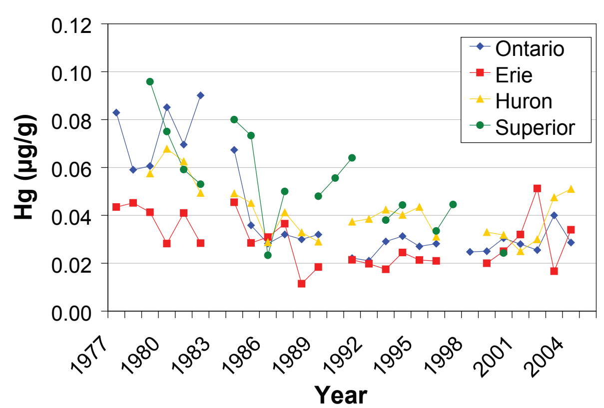

Figure 11. Mercury in composite Environment Canada rainbow smelt, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

indicates that some species of Great Lakes fish are capable of debrominating the deca formulation.

Other Contaminants of Emerging Interest

One of the most widely used brominated flame retardants (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 ecosystems 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 1).

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 1. Lake Ontario food web bioaccumulation of HBCD isomers.
Source: Tomy *et al.* (2004).

Perfluorooctanesulfonate (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 (e.g., Scotchguard™) and fire suppressing foams. It has been identified in whole lake trout samples from all the Great Lakes at concentrations from three 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 to 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, hence there may be periods of increases in contaminant burdens of some fish species.

A recently published, 15-year retrospective Lake Ontario study showed that lake trout embryos and sac fry are very sensitive to toxicity associated with maternal exposures to

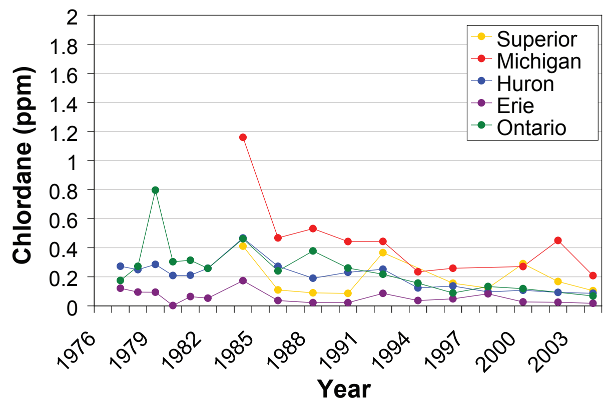

Figure 12. Total Chlordane in Even Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1972 - 2003 µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. *Fish collected between 1972 and 1982 were collected at even year sites only. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

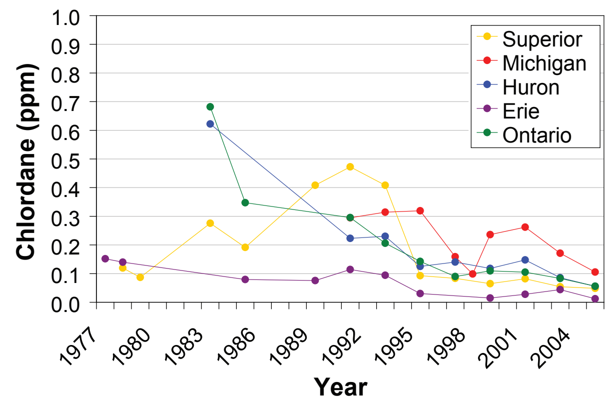

Figure 13. Total Chlordane in Odd Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1991 – 2004 µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

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

Climate change will be an additional pressure in the future . Its potential for regional warming could change the availability of Great Lakes critical habitats, change the productivity of some biological communities, accelerate the movement of contaminants from abiotic sources into biological communities, and effect the composition of biological communities. Associated changes in the concentration of contaminants in the water, critical habitat availability and reproductive success of native and non-native species are also factors that will influence trends in the quantity of toxic contaminants in the Great Lakes basin ecosystem.

Management Implications

Much of the current, basinwide, persistent toxic substance data that is reported focuses on legacy chemicals whose use has been previously restricted through various forms of legislation. There are also a variety of other potentially harmful contaminants at various locations throughout the Great Lakes that are reported in literature. A comprehensive, basinwide 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 (greater than 25 years) 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.

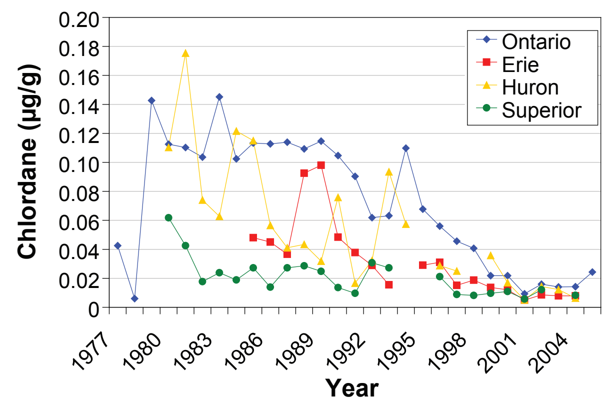

Figure 14. Total Chlordane in 4 to 6 year old individual whole Environment Canada Lake Trout, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

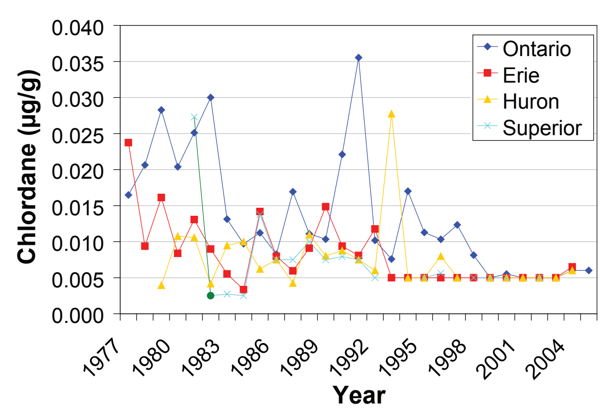

Figure 15. Total Chlordane in composite Environment Canada rainbow smelt, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

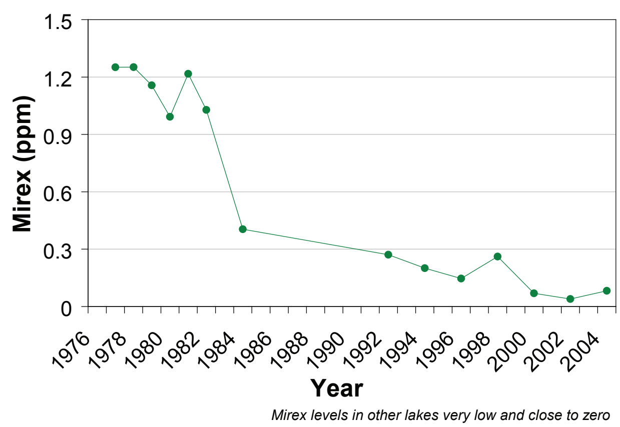

Figure 16. Mirex in Even Year Lake Ontario whole EPA Lake Trout composites, 1972 - 2004 μg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. *Fish collected between 1972 and 1982 were collected at even year sites only. Walleye = 450 -550 mm size range.
Source: U.S. Environmental Protection Agency.

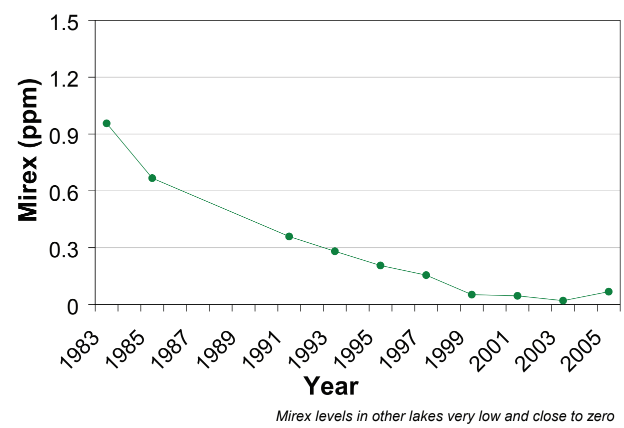

Figure 17. Mirex in Odd Year Lake Ontario whole EPA Lake Trout composites , 1991 – 2005 μg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada				X		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments
Authors: (2008)
Elizabeth Murphy, U.S. Environmental Protection Agency, Great Lakes National Program Office
Sean Backus, Environment Canada

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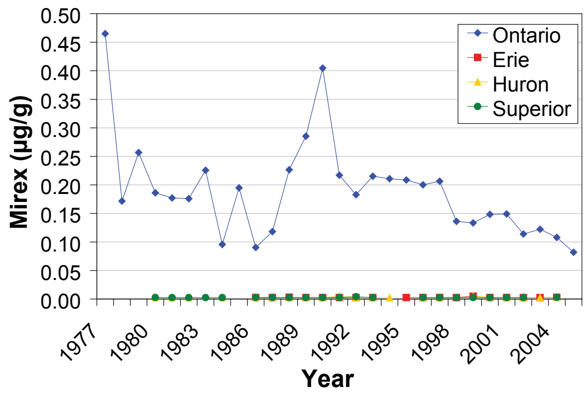

Figure 18. Mirex in 4 to 6 year old individual whole Environment Canada Lake Trout, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

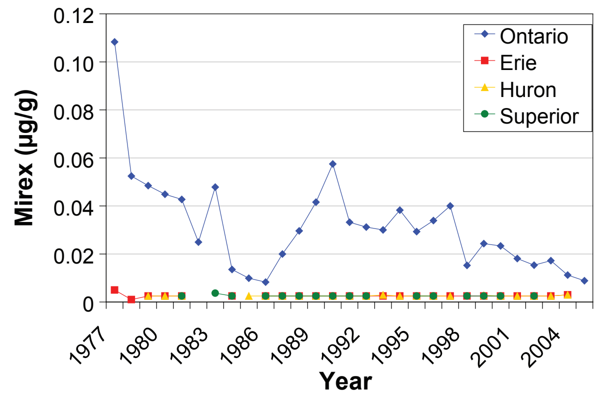

Figure 19. Mirex in composite Environment Canada rainbow smelt, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

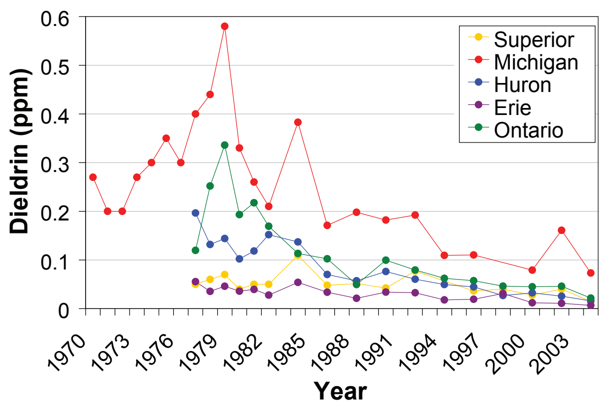

Figure 20. Dieldrin in Even Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1972 - 2003 µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. *Fish collected between 1972 and 1982 were collected at even year sites only. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

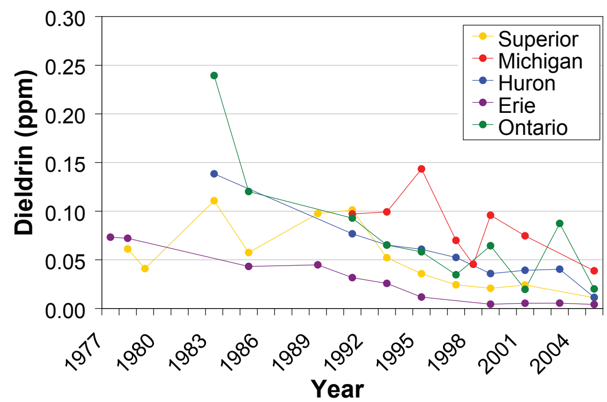

Figure 21. Dieldrin in Odd Year whole EPA Lake Trout composites (Walleye in Lake Erie), 1991 – 2004 µg/g wet weight +/- 95% C.I., composite samples. Lake Trout = 600-700 mm size range. Walleye = 450-550 mm size range.
Source: U.S. Environmental Protection Agency.

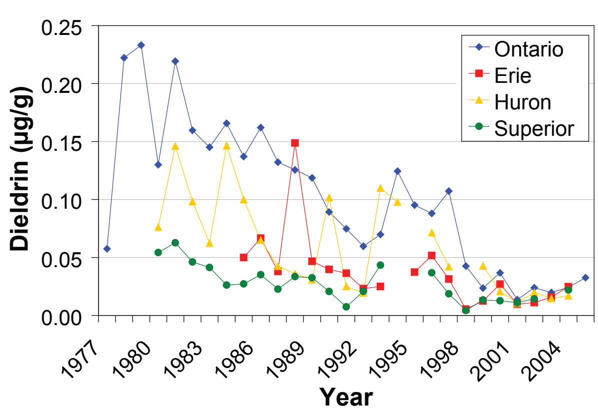

Figure 22. Dieldrin in 4 to 6 year old individual whole Environment Canada Lake Trout, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

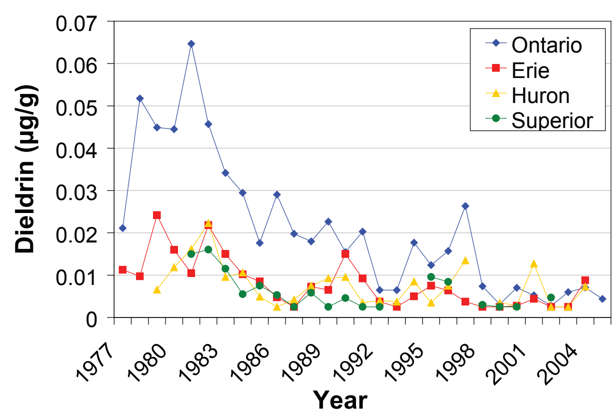

Figure 23. Dieldrin in composite Environment Canada rainbow smelt, collected 1977 through 2005, µg/g wet weight.
Source: Fisheries and Oceans Canada.

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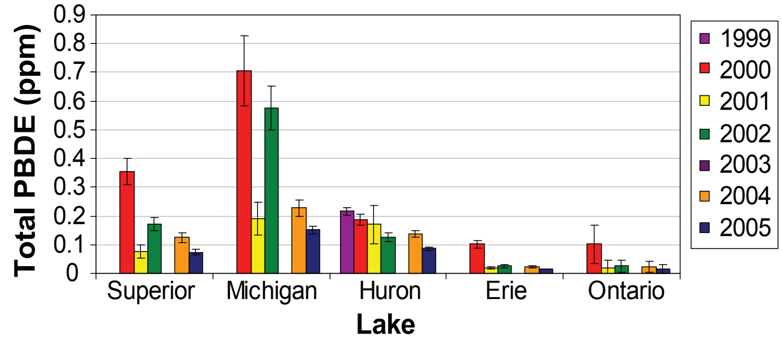

Figure 24. Total PBDE in whole EPA Lake Trout Composites* ** (Walleye in Lake Erie). Total PBDE = BDE 47+99+100+153+154.
* Even year samples collected: Apostle Islands - LS, Saugatuck - LM, Rockport - LH, Middle Bass Island - LE, Oswego - LO.
** Odd year samples collected: Keewenaw Pen. - LS, Sturgeon Bay - LM, Port Austin - LH, Dunkirk - LE, North Hamlin - LO.
Source: U.S. Environmental Protection Agency.

Hexagenia spp.

Indicator #122

Overall Assessment

Status: **Mixed**
Trend: **Mixed to Improving**
Rationale: **To date, only one area (Western Lake Erie) has exhibited any substantial recovery of *Hexagenia* despite anecdotal reports of recovery for many areas in the Great Lakes during the mid- to early 1990s. The cause(s) for population decreases and failed recruitment is not known, but may be related to anoxia caused by residual pollution, viral/parasite cycles, density dependent mechanisms, and changes in dreissenid populations.**

Lake-by-Lake Assessment

Lake Superior
Status: Poor
Trend: Undetermined
Rationale: Lack of time-series and historical information. Baseline (2001) information on the abundance (rare to absent) of *Hexagenia* has been obtained for Duluth Harbor, Minnesota and Wisconsin.

Lake Michigan
Status: Poor
Trend: Undetermined
Rationale: Lack of time-series and historical studies. There have been no scientific conformations of anecdotal reports of *Hexagenia* except for sporadic accounts of adults near the Fox River, and Green Bay, Wisconsin. The absence of *Hexagenia* in Green Bay, Wisconsin was confirmed in 2001.

Lake Huron
Status: Poor
Trend: Undetermined
Rationale: Lack of time-series and historical information. There have been no scientific conformations of anecdotal reports of *Hexagenia* adults. The absence ($<1/m^2$) of *Hexagenia* in Saginaw Bay was confirmed in 2001.

Lake Erie
Status: Western Lake Erie - Good; SW-shore of Central Lake Erie - Mixed
Trend: Western Lake Erie - Mixed to Improving; SW-shore of Central Lake Erie - Deteriorating
Rationale: To date, Western Lake Erie is the only place where *Hexagenia* have been documented to recolonize sediments in the Great Lakes. Along the south shore of Lake Erie, recovery of *Hexagenia* (i.e., appearance and increasing distribution of adults) was brief between 1997 and 2000. No recovery has been noticed along the south shore since 2000.

Lake Ontario
Status: Not Assessed
Trend: Undetermined
Rationale: Mayfly (*Hexagenia*) populations are recovering in some areas. In the early 1990s, there were anecdotal reports of mayflies near the Bay of Quinte, Ontario, but no studies have been performed to verify or refute recovery.

Purpose

- To assess the recovery of *Hexagenia* (burrowing mayflies) in shallow mesotrophic waters of the Great Lakes
- To establish a quantitative goal for the restoration of *Hexagenia* nymphs in mesotrophic waters of the Great Lakes

Ecosystem Objective

Historical mesotrophic habitats should be restored and maintained as balanced, stable, and productive elements of the Great Lakes ecosystem with *Hexagenia* as the key benthic invertebrate organism in the food chain (Edwards and Ryder 1990). In addition, this indicator supports Annex 2 of the Great Lakes Water Quality Agreement (GLWQA) (United States and Canada 1987).

State of the Ecosystem

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

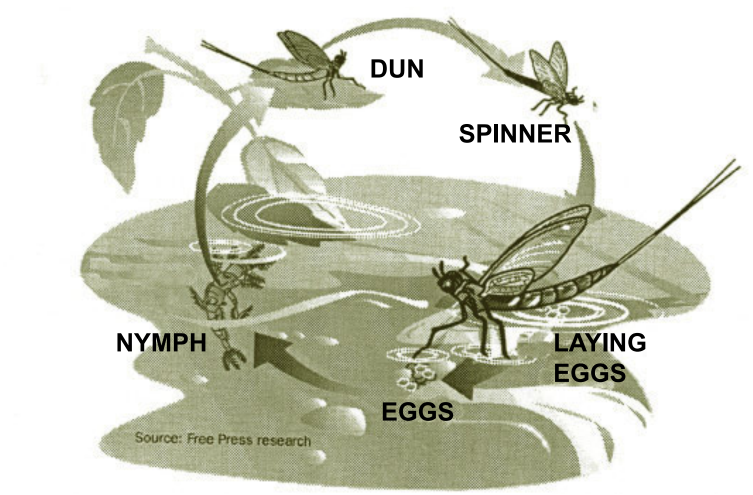

Figure 1. Typical life-cycle of a burrowing mayfly such as *Hexagenia* found in the Great Lakes.
Source: Drawn by Martha Thierry, courtesy of the Detroit Free Press.

Initiation of pollution-abatement programs in the 1970s improved water and sediment quality in *Hexagenia* habitat throughout the Great Lakes, but the recovery of *Hexagenia* populations has been elusive (Krieger *et al.* 1996, Schloesser *et al.* 2000). Then in the early 1990s, soon after the invasion of exotic dreissenid mussels, anecdotal reports occurred of adult *Hexagenia* (winged dun and spinner) in many bays and interconnecting rivers of the Great Lakes after absences of 30 to 60 years (Fig. 1). In the 1990s, anecdotal reports of winged *Hexagenia* mayflies were received from: the south shore of Lake Michigan (near Chicago, IL); the Fox River near Green Bay of Lake Michigan; Saginaw Bay of Lake Huron (near Standish, MI); the south shore of Central Lake Erie (near Sandusky, OH); Presque Isle of Eastern/Central Lake Erie; and, the northern shore in the Bay of Quinte of Lake Ontario (near Picton, ON). To date, only the possible recoveries of *Hexagenia* in Western Lake Erie and along the south shore of Central Lake Erie have been investigated.

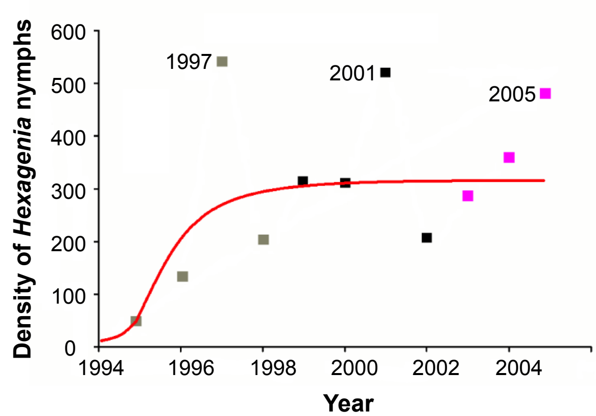

Figure 2. Densities (number/m^2) of *Hexagenia* obtained in three studies (colored markers) in western Lake Erie 1995-2005. Line of abundance fit by eye.
Source: Unpublished data, D. Schloesser.

The first scientific study of the possible recovery of *Hexagenia* was initiated in response to anecdotal reports of adult mayflies in open waters of the western basin of Lake Erie by scientists on Environment Canada's research vessel *CCGS Limnos* in 1992 (D. Schloesser, personal communication). Nymphs were confirmed in sediments at very low densities (ca. nine nymphs/m^2) in 1993, and intensive studies began in 1995 (Fig. 2, Krieger *et al.* 1996, Schloesser unpublished data). Densities of nymphs increased between 1995 and 1997 and then decreased between 1997 and

1998. This pattern of increasing densities followed by a large decrease occurred again between 2001 and 2002. A population study of *Hexagenia* revealed that sharp declines in densities were partly attributable to failed young-of-the-year (YOY) recruitment (Fig. 3, Bridgeman *et al.* 2005, Schloesser unpublished data). No YOY nymphs were found in 1997. Recruitment increased between 1997 and 1999 then declined to seven YOY/m^2 in 2002. A dramatic increase in YOY recruitment occurred between 2002 and 2003. Recruitment was relatively high between 2003 and 2006, although it declined steadily between those years. Guarded optimism is warranted over the recovery of mayflies in Western Lake Erie and elsewhere in the Great Lakes because initial recovery and density fluctuations also occurred along the south shore of Central Lake Erie between 1997 and 2000. By 2004 scientific investigations indicated that a recovery of *Hexagenia* did not occur along the shore of south Central Lake Erie.

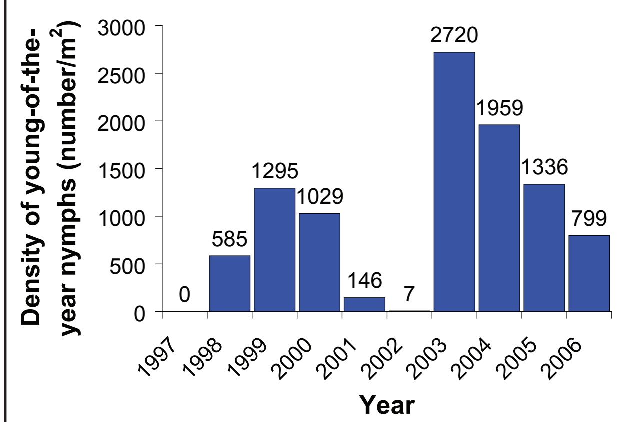

Figure 3. Recruitment of young-of-year *Hexagenia* in western Lake Erie 1997-2006.
Source: Schloesser and Nalepa (2001); Bridgeman *et al.* (2005).

Pressures

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

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

Management Implications

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

The recovery of *Hexagenia* in Western Lake Erie reminds us of an outstanding feature associated with using *Hexagenia* as an indicator of ecosystem health – the massive swarms of winged adults that are typical of healthy, productive *Hexagenia* populations. These swarms are highly visible to the public who use them to judge success of pollution abatement programs by seeing a 'real' species that signifies the return of a 'real' habitat to a desirable condition in the Great Lakes. This public perception has influenced target values set by management for the recovery of *Hexagenia* in Western Lake Erie (i.e., imperiled and good above excellent, Fig. 4). However, values above excellent are based on societies' perception of excessive en masse emergences of winged *Hexagenia* which affect electrical power generation, vehicle traffic, and outdoor activities. These values may not represent the best scientific information for the historic, natural carrying capacity of *Hexagenia* in mesotrophic waters. For example, the target value of excellent is based on

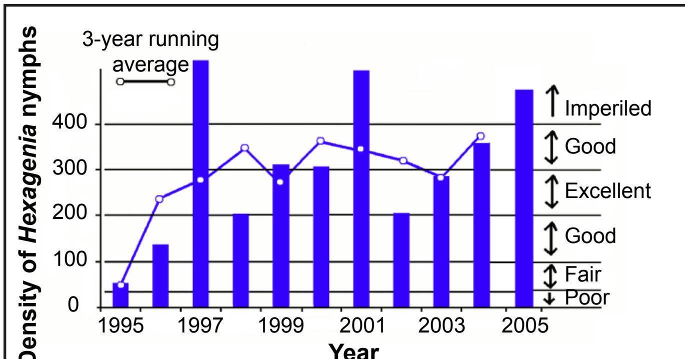

Figure 4. Densities (number/m^2) of *Hexagenia*, three-year running average of densities, and subjective target-reference values of desired abundance (i.e., poor, fair, good, etc.) in western Lake Erie.
Source: Based on Ohio Lake Erie Commission (2004).

historical densities, a desire to return the system to an earlier, more 'pristine' condition and to provide prey for valuable fishes. Yet, there is no scientific information that indicates densities of nymphs above 'excellent' would be in conflict with historical data, previous system conditions, and prey availability to fishes.

Comments from the author(s)
In the early 20th century, *Hexagenia* were believed to be abundant in all mesotrophic waters of the Great Lakes including Green Bay (Lake Michigan), Saginaw Bay (Lake Huron), Lake St. Clair, Western Lake Erie, Bay of Quinte (Lake Ontario), and portions of interconnecting rivers and harbors. Thirty years of pollution abatement programs may have allowed *Hexagenia* to return to other areas of the Great Lakes besides Western Lake Erie as evidenced by anecdotal sightings of winged mayflies in the 1990s. However, anecdotal reports have slowed and only one scientific study (Krieger *et al.* 2007) has been performed to confirm anecdotal reports, and that study in Central Lake Erie could not verify a sustained *Hexagenia* recovery.

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

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin					X	
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report				X		
Clarifying Notes: Most data on file at the Great Lakes Science Center, Ann Arbor, Michigan. Data sources rest primarily with the author.						

Acknowledgments
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Abundances of the Benthic Amphipod *Diporeia* spp.

Indicator #123

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**
Rationale: **Abundances of the benthic amphipod *Diporeia* spp. continue to decline in Lake Michigan, Lake Huron, and Lake Ontario. Past studies of trends in Lake Superior were somewhat conflicting, but recent data indicate that declines are not occurring. *Diporeia* are currently extirpated or very rare in Lake Erie.**

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Unchanging
Rationale: One long-term monitoring program showed that *Diporeia* abundances were declining in offshore areas, but remained unchanged in the nearshore. Recent data collected by this monitoring program now shows that the population in offshore areas has increased, demonstrating that relatively large annual fluctuations can occur. Other sampling programs show no overall trend.

Lake Michigan
Status: Poor
Trend: Deteriorating
Rationale: *Diporeia* abundances continue to decline in Lake Michigan. A recent lakewide survey (in 2005) indicated abundances were lower by 84% compared to abundances found in 2000. *Diporeia* are now completely gone from depths less than 80 m (263 ft) over most of the lake, and abundances are in the state of decline at depths greater than 80 m (263 ft).

Lake Huron
Status: Poor
Trend: Deteriorating
Rationale: *Diporeia* abundances continue to decline in Lake Huron. The most recent lakewide survey in the main basin (in 2007) indicated that overall abundances were lower by 93% compared to abundances found in 2000 (Fig. 1). *Diporeia* are now completely gone or rare at depths less than 60 m (197 ft) and continue to decline at depths greater than 60 m (197 ft).

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: Because of shallow, warm waters, *Diporeia* are naturally not present in the Western and Central basins. *Diporeia* declined in the Eastern basin beginning in the early 1990s and have not been found since 1998.

Lake Ontario
Status: Poor
Trend: Deteriorating
Rationale: In one 2005 survey of 11 sites, *Diporeia* declined at two sites and increased slightly at two sites compared to 2004, and remained absent at six sites in both years. In another survey of 14 sites in 2005, changes were variable. It was not found at sites less than 90 m (295 ft) over most of the lake. Between 2005 and 2007 several sites along the south side as deep as 150 m (492 ft) had lost their populations.

Purpose

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

Ecosystem Objective

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

State of the Ecosystem

Background

This glacial-marine relic was once the most abundant benthic organism in cold, offshore regions (greater than 30 m (98 ft) of each of the lakes. It was present, but less abundant in nearshore regions of the open lake basins, and naturally absent from shallow, warm bays, basins, and river mouths. *Diporeia* occurs in the upper few centimeters 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 Great Lakes fish; in particular by many forage fish species, which themselves 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 (*Salvelinus namaycush*). Also, lake whitefish (*Coregonus clupeaformis*), an important commercial species, feeds heavily on *Diporeia*. Thus, *Diporeia* was an important pathway by which energy was cycled through the ecosystem, and a key component in the food web of offshore regions. The importance of this organism is recognized in the Great Lakes Water Quality Agreement (GLWQA): Supplement to Annex 1 – Specific Objectives (United States and Canada 1987).

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 a state of dramatic decline in Lake Michigan, Lake Ontario, and Lake Huron (Fig. 1, 2), and they are extirpated or very rare in Lake Erie. Recent results of monitoring programs in Lake Superior indicate that the

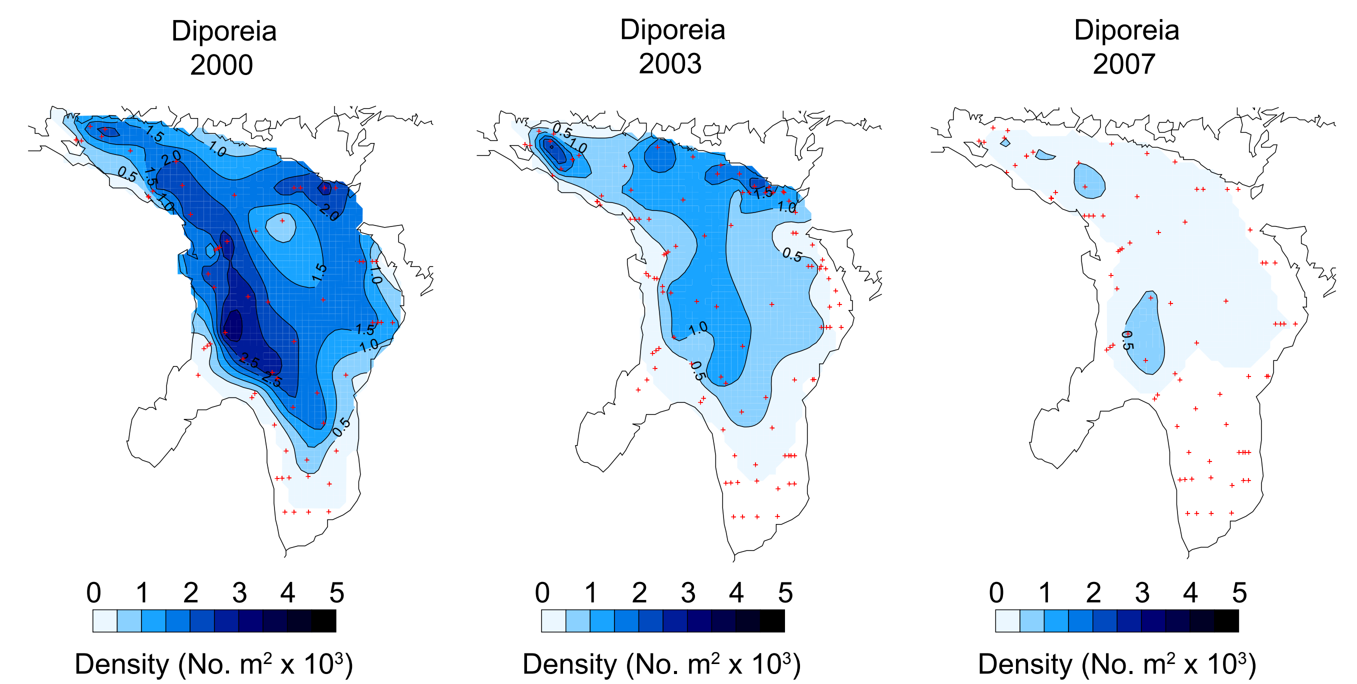

Figure 1. Distribution and abundance (number per square meter) of the amphipod *Diporeia* spp. in Lake Huron in 2000, 2003, and 2007. Small crosses indicate location of sampling stations.
Source: National Oceanic & Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory..

population is not declining, but can be highly variable. In all the lakes except Lake Superior, abundances have decreased progressively from shallow to deeper areas. Initial declines were first observed in all lake areas within two to three years of when zebra mussels (*Dreissena polymorpha*) or quagga mussel (*D. bugensis*) first became established. These two species were introduced into the Great Lakes in the late 1980s via the ballast water of ocean-going ships. Reasons for the negative response of *Diporeia* to these mussel species are not entirely clear. One hypothesis is that dreissenid mussels are out-competing *Diporeia* for available food. That is, large mussel populations filter food material before it reaches the bottom, thereby decreasing amounts available to *Diporeia*. However, evidence suggests that the reason for the decline is more complex than a simple decline in food because *Diporeia* have completely disappeared from areas where food is still settling to the bottom and where there are no local populations of mussels. Also, individual *Diporeia* show no signs of starvation before or during population declines. Further, *Diporeia* and *Dreissena* apparently coexist in some lakes outside of the Great Lakes (i.e., Finger Lakes in New York).

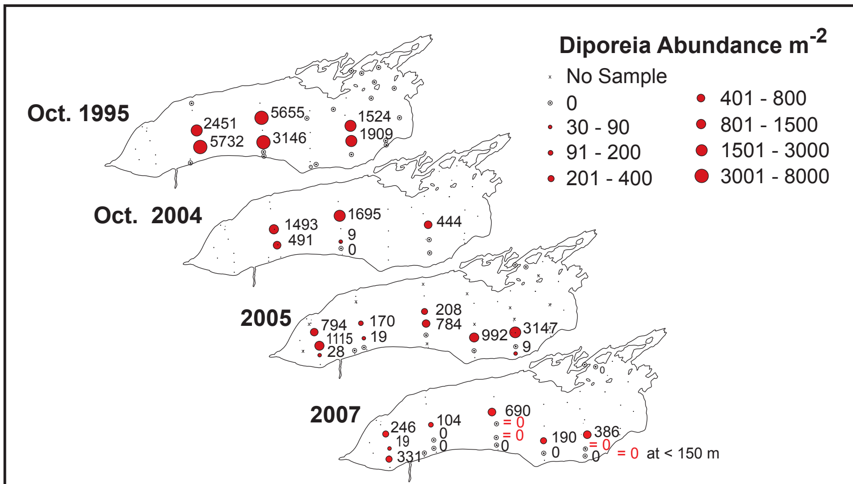

Figure 2. Distribution and abundance (number per square meter) of the amphipod *Diporeia* spp. in Lake Ontario in 1995, 2004, 2005, and 2007.
Source: Great Lakes Lab for Fisheries & Aquatic Sciences, Fisheries & Oceans.

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 Lake Michigan, Lake Huron, and Lake Ontario, zebra mussels are most abundant at depths less than 50 m (164 ft), and *Diporeia* are now gone or rare from lake areas as deep as 90 m (295 ft). Recently, quagga mussel populations have increased dramatically in each of these lakes and are occurring at deeper depths than zebra mussels. The decline of *Diporeia* at depths greater than 90 m (295 ft) can be attributed to the expansion of quagga mussels to these depths.

Management Implications

The continuing decline of *Diporeia* has strong implications to the Great Lakes food web. As noted, many fish species rely on *Diporeia* as a major prey item, and the loss of *Diporeia* will likely have an impact on these species. Responses may include changes in diet, movement to areas with more food, or a reduction in weight or energy content. Implications to populations include changes in distribution, abundance, growth, recruitment, and condition. Recent evidence suggests that fish are already being affected. For instance, growth and condition of an important commercial species, lake whitefish, has declined significantly in areas where *Diporeia* abundances are low in Lake Michigan, Lake Huron, and Lake Ontario. Also, studies show that other species such as alewife (*Alosa pseudoharengus*), slimy sculpin (*Cottus cognatus*), and bloater (*Coregonus hoyi*) have been affected. Management agencies must know the extent and implications of these changes when assessing the current state and future trends of the fishery. Any proposed rehabilitation of native fish species, such as the re-introduction of deepwater ciscoes (*Coregonus johannae*) in Lake Ontario, requires knowledge that adequate food, especially *Diporeia*, is present.

Comments from the author(s)

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

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

Acknowledgments

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Last Updated
State of the Great Lakes 2009

External Anomaly Prevalence Index for Nearshore Fish

Indicator #124

Overall Assessment

Status:	**Poor**
Trend:	**Unchanging**

Lake-by-Lake Assessment

Lake Superior
Status: Not assessed
Trend: Undetermined

Lake Huron
Status: Not assessed
Trend: Undetermined

Lake Michigan
Status: Not assessed
Trend: Undetermined

Lake Erie
Status: Poor
Trend: Unchanging

Lake Ontario
Status: Poor
Trend: Unchanging

Purpose

- To assess select external anomalies in nearshore fish
- To identify nearshore areas that have populations of benthic fish exposed to contaminated sediments
- 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 (United States and Canada 1987).

State of the Ecosystem

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

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

Surveys conducted in 1999 and 2000 in the Detroit, Ottawa, Black, Cuyahoga, Ashtabula, Buffalo, and Niagara Rivers and at Old Woman Creek in Lake Erie demonstrated that external

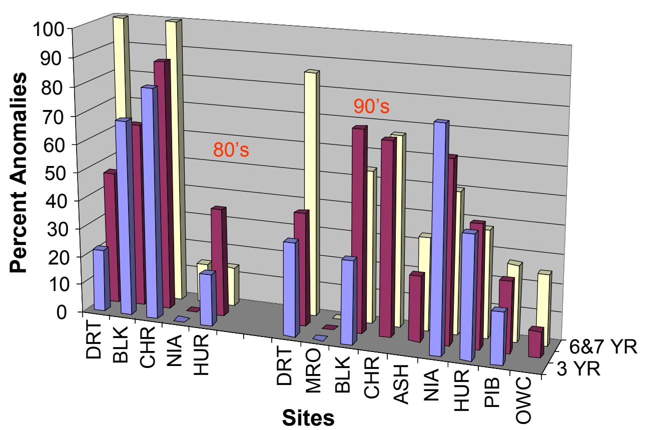

Figure 2. Age of brown bullhead at Lake Erie sites from 1986-87 and 1998-2000 collections in relation to combined external anomalies.
Age groups; age 3, ages 4&5, ages 6&7.
Source: S.B. Smith, unpublished data.

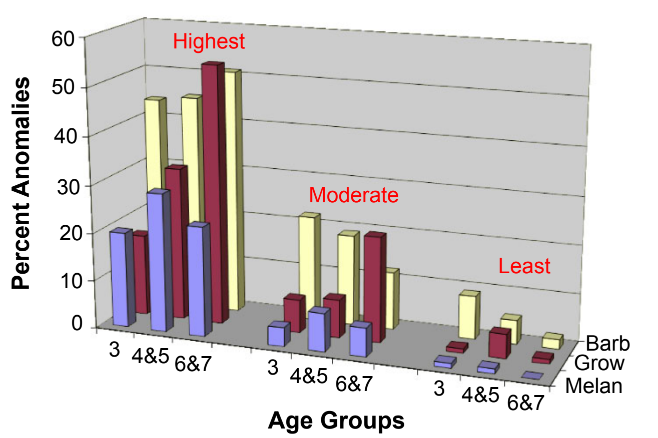

Figure 3. External anomalies (Melanoma, Raised Growth on body and lips, and Barbell abnormalities) in relation to sites classified for sediment contaminants and BB morphology from all collections in the 1980s and 1990s.
Source: S. B. Smith, unpublished data.

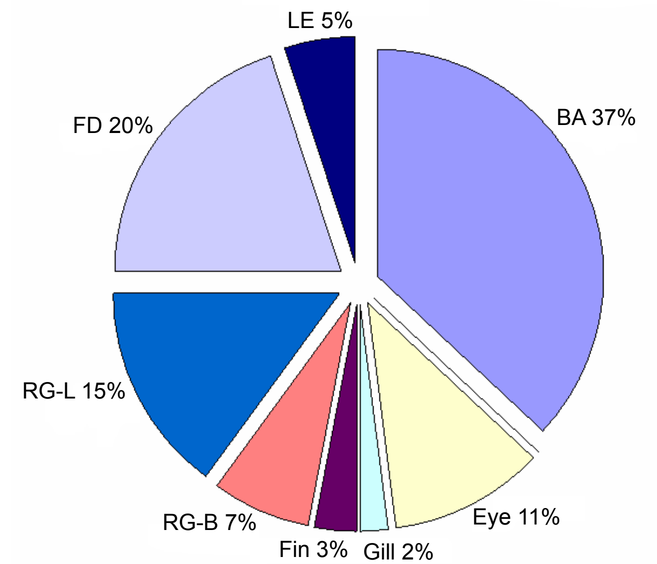

Figure 1. External Anomalies on brown bullhead collected from Lake Erie from the 1980s through 2000. BA- barbel abnormalities, RG- raised growth (body and lip), FD-focal discoloration, LE-lesion (total ca. 2400 fish). Units are µg/mg protein.
Source: Great Lakes Science Center, Ann Arbor, MI.

raised growths are positively associated with both PAH metabolites in bile and in PAH concentrations in sediment. The association with PAH metabolites in bile (Fig. 4) is stronger than that with total PAH concentrations in sediments (Fig. 5). Bile metabolite concentrations may be a better estimate of potential exposure of PAHs to individual fish than concentrations in sediments. The EAPI indicates the impacts from the exposure to individual fish from the PAHs as well as other compounds in the mixtures of compounds that may be present in sediments. Barbel deformities (Fig. 5) also showed a positive correlation with total PAH levels in sediment. In addition to the locations listed above, the Huron River and Presque Isle Bay sites all showed a statistically significant correlation between external raised growths and concentration of heavy metals in sediment (Fig. 6).

Pressures

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

Management Implications

The EAPI provides managers and researchers with a tool to monitor contaminant impacts to the fish populations in Great Lakes AOCs. Additional remediation to clean up contaminated sediments at Great Lakes AOCs will help to reduce rates of external anomalies. The EAPI, particularly for brown bullheads and white suckers and the inclusion of a single common data base will help environmental managers to follow trends in fish population health and to determine the status of AOCs that may be considered for delisting. Delisting principals and guidelines have been adopted by the U.S. Policy Committee (2001).

Comments from the author(s)

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

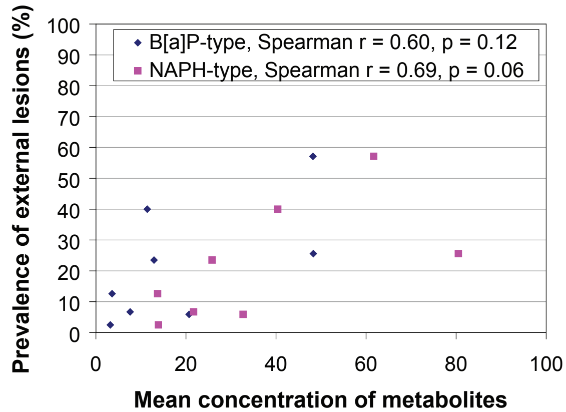

Figure 4. Prevalence of external raised growths in brown bullhead from Lake Erie tributaries compared to PAH metabolite concentrations in bile (B[P] and NAPH-type). Units are µg/mg protein.
Source: Yang and Baumann, unpublished data.

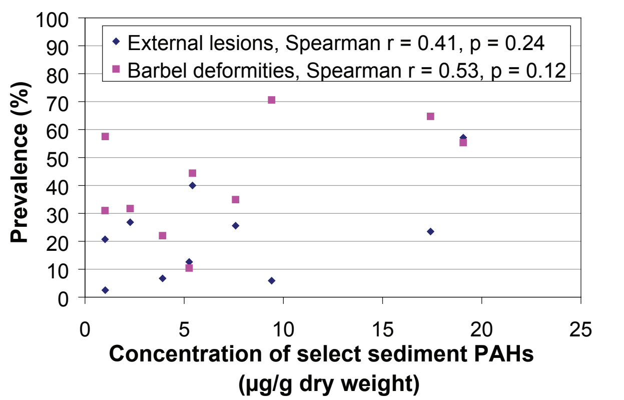

Figure 5. Prevalence of external raised growths and barbel deformities in brown bullhead from Lake Erie tributaries compared to PAH concentrations in sediment.
Source: Yang and Baumann, unpublished data.

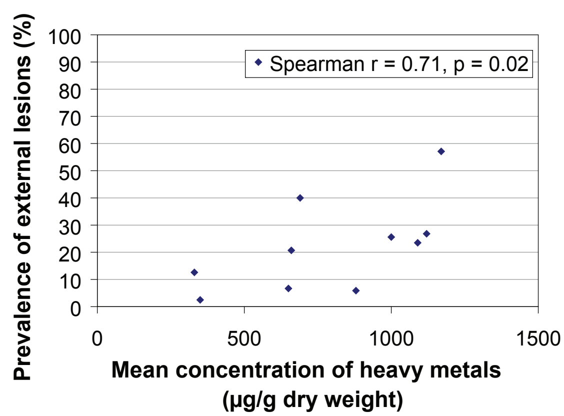

Figure 6. Prevalence of external raised growths in brown bullhead from Lake Erie tributaries compared to concentrations of heavy metals in sediment.
Source: Yang and Baumann, unpublished data.

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

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Last Updated
State of the Great Lakes 2007

Status of Lake Sturgeon in the Great Lakes
Indicator #125

Overall Assessment

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

Lake-by-Lake Assessment

Lake Superior
Status: Mixed
Trend: Improving or Undetermined
Rationale: Lake sturgeon abundance shows an increasing trend in a few remnant populations and where stocked in the Ontonagon and St. Louis rivers. Lake sturgeon currently reproduce in at least 10 of 22 known historic spawning tributaries.

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

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

Lake Erie
Status: Mixed
Trend: Improving and Undetermined
Rationale: Lakewide incidental catches since 1992 indicate a possible improvement in their status in Lake Erie. Spawning occurs in three know locations in the basin, all located in the connecting waters between Lakes Huron and Erie. The Huron-Erie Corridor supports a robust population of all age classes. The Western basin of Lake Erie, the Detroit River east of Fighting Island, the North Channel of the St. Clair River and Anchor Bay in Lake St. Clair appear to be nursery areas for juveniles and foraging areas for adults.

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

Purpose

- To assess the presence and abundance of lake sturgeon in the Great Lakes and their connecting waterways and tributaries
- To infer the health and status of the nearshore benthivore fish community that does, could or should include lake sturgeon

Ecosystem Objective

Conserve, enhance or rehabilitate self-sustaining populations of lake sturgeon where the species historically occurred and at a level that will permit all state, provincial and federal delistings of classifications that derive from degraded or impaired populations, e.g., threatened, endangered or at risk species. Lake sturgeon is identified as an important species in the Fish Community Goals and Objectives for each of the Great Lakes. Lake Superior has a lake sturgeon rehabilitation plan, and many of the Great Lakes states have lake sturgeon recovery or 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, Fig. 1).

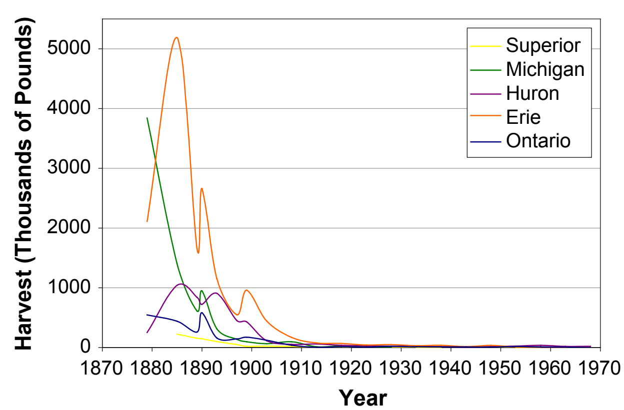

Figure 1. Historic lake sturgeon harvest from each of the Great Lakes.
Source: Baldwin *et al.* 1979.

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 is now extirpated from many tributaries and waters where they once spawned and flourished (Figs. 2 and 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 waters of the Great Lakes.

Status of Lake Sturgeon

Efforts continue by many agencies and organizations to gather information on remnant spawning populations in the Great Lakes. Most sturgeon populations continue to sustain themselves at a small fraction of their historical abundance. In many systems, access to spawning habitat has been blocked, and other habitats have been altered. However, there are remnant populations in each basin of the Great Lakes, and some of these populations are large in number (tens of thousands of fish, Fig. 3). Genetic analysis has shown that Great Lakes populations are regionally structured and show significant diversity within and among lakes (DeHaan *et al.* 2006, Welsh *et al.* 2008).

Lake Superior

The fish community of Lake Superior remains relatively intact in comparison to the other Great Lakes (Bronte *et al.* 2003). Historic and current information indicates that at least 22 Lake Superior tributaries supported spawning lake sturgeon populations (Harkness and Dymond 1961, Auer 2003, Quinlan 2007). Lake sturgeon currently reproduce in at least 10 tributaries. Populations in the Sturgeon River, Michigan, and Bad River, Wisconsin, meet rehabilitation plan criteria for self-sustaining populations (Auer 2003, Auer and Baker 2007, Great Lakes Indian Fish and Wildlife Commission (GLIFWC) and USFWS unpublished data, Quinlan 2007). Improvements in assessment techniques and stocking have resulted in increases in estimated lakewide abundance (Auer and Baker 2007, Schram 2007, and GLIFWC unpublished data). Using hydroacoustic technology, the estimated number of lake sturgeon in the annual spawning run at Sturgeon River, Michigan increased by nearly 100 individuals to range from 350 to 400 adults (Auer and Baker 2007), Genetic analysis has shown that lake sturgeon populations in Lake Superior are significantly different from those in the other Great Lakes (Welsh *et al.* 2008).

Annual assessments were established in key embayments and nearshore waters including Pigeon Bay, Minnesota/Ontario, and in Keweenaw Bay and near the Ontonagon River, Michigan. Habitat (substrate type and water depth) for adult and juvenile fish was geo-referenced and quantified using hydroacoustics in the Kaministiquia River, Ontario (Biberhofer and Prokopec 2005) and Bad River (Cholwek *et al.* 2005). Habitat preference of stocked sturgeon is being studied in the Ontonagon and St. Louis Rivers using radio telemetry (Fillmore 2003, 1854 Authority unpublished data). Due to potential for overexploitation, sport fishing regulations in Ontario waters have been changed to eliminate harvest. There remains a prohibition of commercial harvest of lake sturgeon in Lake Superior. Regulation of recreational and subsistence/home use harvest in Lake Superior varies by agency.

Despite limited progress, challenges remain. Spawning runs are absent in 12 of 22 historic spawning tributaries, and only two populations meet targets identified in the 2003 Rehabilitation Plan. Overall, lake sturgeon abundance remains a small fraction of historical abundance, estimated at 870,000 (Hay-Chmielewski and Whelan 1997) and basic abundance and biological data are unavailable for many stocks.

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 10,000 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 nine tributaries having unimpeded connections to Lake Michigan (Schneeberger *et al.* 2005, Elliott 2008). Two rivers, the Menominee and Peshtigo, appear to support annual spawning runs of 200 or more adults, and five rivers, the Manistee, Muskegon, Grand, Fox and Oconto, appear to support annual spawning runs of between 25 and 75 adults. Successful reproduction has been documented in all seven of these rivers, and age 0 juveniles can be captured regularly in several of these rivers. Recent recruitment estimates have been made from research efforts in the Peshtigo River indicating that in some years, several hundred fall recruits are produced from that system (Caroffino *et al.* 2007), and research and assessment efforts in the Manistee and Muskegon rivers indicate significant recruitment from those systems as well (Smith, MDNR, personal communication). In addition, abundance of spawners in some rivers appears to have increased in the last decade, indicating that increased recruitment may have been occurring for several years in some rivers. Two other rivers, the Manistique and Kalamazoo, appear to have annual spawning runs of less than 20 fish. Some lake sturgeon have been observed during spawning times in a few other Lake Michigan tributaries such as the St. Joseph and Millecoquins, and near some shoal areas where sturgeon are thought to have spawned historically. It is not known if or how regularly spawning occurs in these systems, and their reproductive status is uncertain. A large self-sustaining population exists in the Lake Winnebago system upstream of the lower Fox River.

Active management in the form of reintroduction stocking and rearing assistance has been implemented in seven Lake Michigan basin tributaries. Commencing in 2005, lake sturgeon have been reared from eggs using streamside rearing facilities and stocked as fingerlings into the Milwaukee, Manitowoc, Cedar, and Whitefish Rivers where sturgeon have been considered extirpated for some time. Over the next 25 years, these reintroductions are intended to rebuild self-sustaining populations that use these rivers to spawn. A streamside rearing facility also is being used to increase the survival of naturally produced larvae in the Manistee River since 2003 (Holtgren *et al.* 2007). Stocking also has been conducted in the upper Menominee River and in the Winnebago system for several years. Though limited recreational harvest is allowed in both the upper Menominee River and the Winnebago system, no harvest is allowed from other Lake Michigan tributaries or from Lake Michigan. Habitat evaluations have been conducted in many sturgeon tributaries within the Lake Michigan basin (Daugherty *et al.* 2009), and improvements in flow conditions and increased planning for fish passage at barriers have the potential to continue to improve habitat conditions in several tributaries.

Lake Huron

Lake sturgeon populations continue to be well below historical levels. Spawning has been identified in the Garden, Mississaugi and Spanish Rivers in the North Channel, in the Nottawasaga River in Georgian Bay and in the Rifle River in Saginaw Bay. Adult spawning populations for each of these river systems are estimated to be in the tens of individuals and are well below rehabilitation targets (Hay-Chmielewski and Whelan 1997, Holey *et al.* 2000). Research in the Saginaw River Watershed in 2005–2007 indicated that lake sturgeon are no longer spawning in that watershed, although sufficient spawning habitat does exist below the Dow Dam on the Tittabawassee River and below the Hamilton Dam on the Flit River. Research is ongoing on the St. Mary's River system and it is unclear if lake sturgeon are using the system for spawning or if the fish are staging there prior to traveling up adjacent tributaries to spawn. The project is ongoing and will continue through 2009. Similar research is being planned for the Rifle River, one of Michigan's last unimpeded rivers. Barriers on Michigan's remaining tributaries to Lake Huron continue to be a major impediment to successful rehabilitation.

Stocks of lake sturgeon in Lake Huron are monitored primarily through the volunteer efforts of commercial fishers cooperating with the various resource management agencies. To date the combined efforts of researchers in U.S. and Canadian waters have resulted in over 6,600 sturgeon tagged in Saginaw Bay, southern Lake Huron, Georgian Bay and the North Channel, with relatively large stocks of mixed sizes being captured at each of these general locations. Tag recoveries and telemetry studies indicate that lake sturgeon are moving within and between jurisdictional boundaries and between lake basins, supporting the need for more cooperative management between the states and between the United States and Canada. As of June 2008, recreational harvest of lake sturgeon in Ontario waters of Lake Huron have been reduced to a zero catch and possession limit and the Ontario Ministry of Natural Resources is moving to a zero harvest limit with the commercial fisheries. Recreational and commercial harvest remains closed in U.S. waters. Traditional use of lake sturgeon by Aboriginal groups in Ontario varies by location and the Ontario Ministry of Natural Resources and Department of Fisheries and Oceans are working with them in an effort to manage those stocks in a sustainable manner.

Lake Erie

Lake sturgeon populations continue to be well below historical levels with the exception of the stocks located in the connecting waters between Lakes Huron and Erie. Spawning has been identified at two locations in the St. Clair River and at one location in the Detroit River (Manny and Kennedy 2002). Tag recovery data and telemetry research indicate that a robust lake sturgeon stock of approximately 15,000 to 20,000 fish reside in the North Channel of the St. Clair River and Lake St. Clair (Mike Thomas, MDNR, personal communication). The North Channel of the St. Clair River, Anchor Bay in Lake St. Clair, the Detroit River (east of Fighting Island), and the Western basin of Lake Erie have been identified as nursery areas as indicated by consistent catches in commercial and survey fishing gears. In the Central and Eastern basins of Lake Erie, lake sturgeon are scarcer with only occasional catches of sub-adult or adult lake sturgeon in commercial fishing nets and none in research nets. A botulism-related die off in 2001 and 2002 near Buffalo indicate a possible decline in population

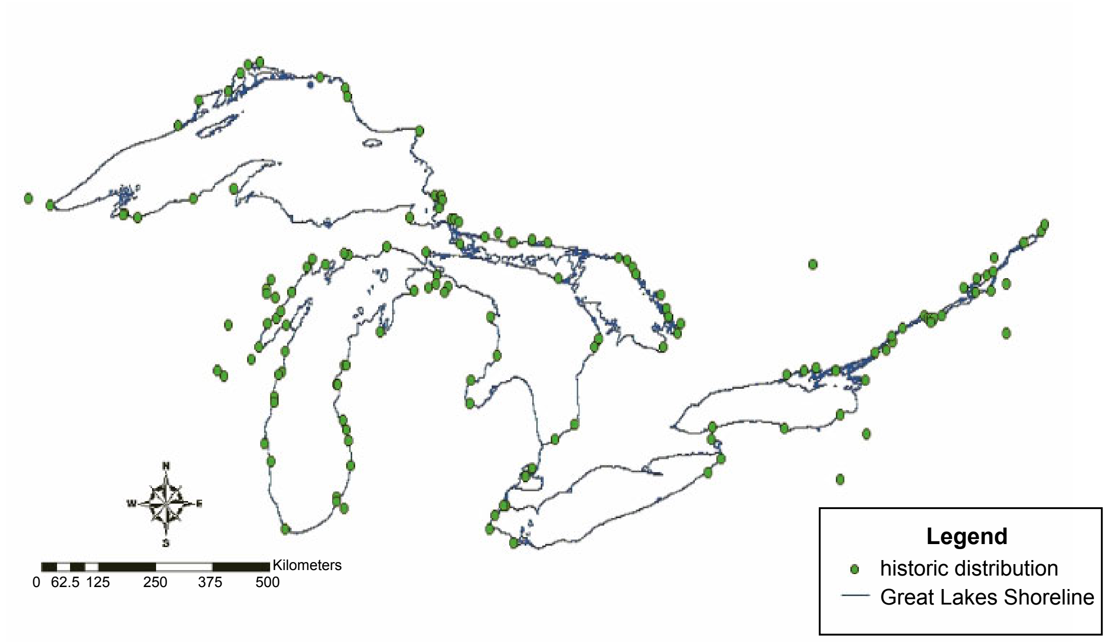

Figure 2. Historic distribution of lake sturgeon.
Source: Zollweg *et al.* 2003.

abundance of lake sturgeon in the Central and Eastern basin of Lake Erie. However, anglers and divers continue to report sturgeon sightings in the upper Niagara River and into the lake. Survey work conducted in 2005 and 2006 indicated that no lake sturgeon spawning is taking place in the Maumee River (OH) although spawning and nursery habitat would support a reintroduced population (Boase, unpublished data). Research efforts will continue to focus on identifying new spawning locations, genetic difference between stocks, habitat requirements, and migration patterns. In U.S. waters of the St. Clair River and Lake St. Clair, recreational harvest of lake sturgeon is allowed with the following restrictions: only fish between 105 and 125 cm (42-50 in) may be harvested, one fish per season, with an open season from July 16–September 30 and a catch and release season from October 1–November 30. No recreational harvest is allowed in any of the other U.S. or Canadian jurisdictional waters of Lake Erie or the connecting waters (St. Clair and Detroit rivers and Lake St. Clair). The Ontario Ministry of Natural Resources is working to close the one remaining lake sturgeon commercial fishery located in Lake St. Clair which should be implemented by 2009. Traditional use of lake sturgeon by Aboriginal groups in Ontario varies by location and the Ontario Ministry of Natural Resources and Department of Fisheries and Oceans are working with them in an effort to manage those stocks in a sustainable manner.

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. The New York State Department of Environmental Conservation initiated a stocking program in 1995 to recover lake sturgeon populations. Lake sturgeon has been stocked in the St. Lawrence River and some of its tributaries, inland lakes in New York, and the Genesee River. There are sizeable populations within the St. Lawrence River system, most notably Lac St. Pierre and the Des Prairies and St. Maurice Rivers. However, access is inhibited for many of the historical spawning grounds in tributaries by small dams and within the St. Lawrence River by the Moses-Saunders Dam.

Pressures

Low numbers or lack of fish (where extirpated) is itself 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 of eggs and newly hatched lake sturgeon by non-native predators may also be a problem. The genetic structure of remaining populations has been studied by university researchers and fishery managers, and this information will be used to guide future management decisions. With

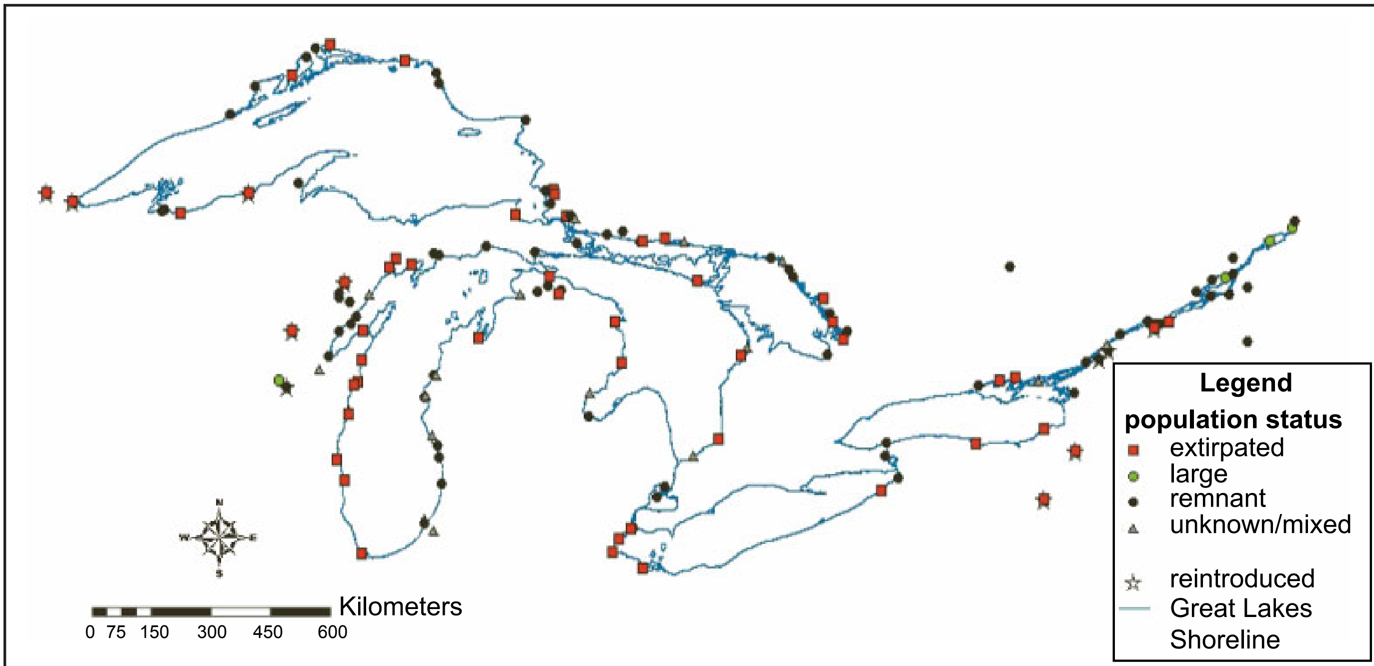

Figure 3. Current distribution of lake sturgeon.
Source: Zollweg *et al.* 2003.

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 many of the Great Lakes is the ecosystem changes that are resulting from high densities of invasive species such as dreissenid mussels and round gobies, and the presumed related spread of botulism Type E which has produced die-offs of lake sturgeon in most years since 2001.

Management Implications

Lake sturgeon is an important native species that is listed in the Fish Community Goals and 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, Zollweg *et al.* 2003, Quinlan *et al.* 2005, Boase *et al.* 2008) 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 and recruitment levels for juvenile lake sturgeon (ages 0 to 2). Several agencies are also working in concert on reintroduction and rearing assistance programs to strengthen and reintroduce lake sturgeon into various waters where populations are lacking or at risk from further declines.

Comments from the author(s)

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

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Commercial/Industrial Eco-Efficiency Measures
Indicator #3514

This indicator report was last updated in 2003.

Overall Assessment

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

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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 (World Business Council on Sustainable Development (WBCSD) 2002)). In addition, the evaluation includes an enumeration of specific initiatives that are targeted toward one or more of the elements of eco-efficiency success (material intensity, energy intensity, toxic dispersion, recyclability and product durability (WBCSD 2002)).

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

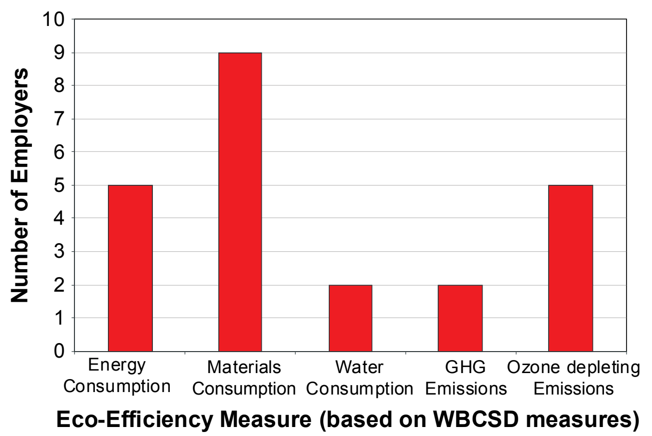

Figure 1. Number of the 24 largest employers in the Great Lakes basin that publicly report eco-efficiency measures. GHG=green house gas.
Source: WBCSD = World Business Council for Sustainable Development.

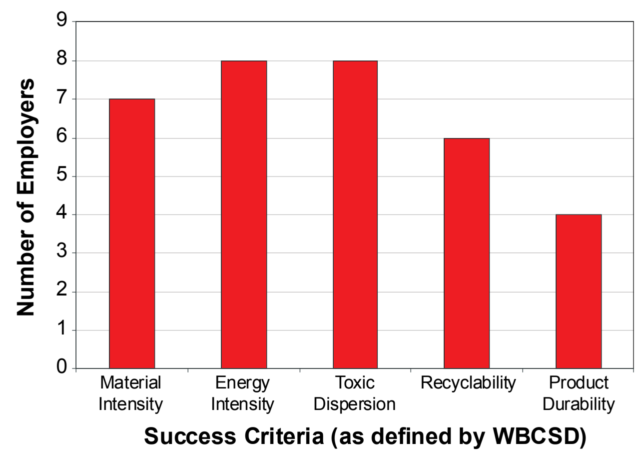

Figure 2. Number of the 24 largest employers in the Great Lakes basin that publicly report initiatives related to eco-efficiency success criteria.
Source: WBCSD = World Business Council for Sustainable Development.

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 United States and Nortel Networks in Canada, have shown strong leadership in comprehensive, easily accessed, public reporting on environmental performance. Others, such as Haworth Inc. and Quad/Graphics, have shown distinct creativity and innovation in implementing measures to reduce their environmental impact. The concept of eco-efficiency was defined in 1990, but was not widely accepted until several years later. Specific data on commercial/industrial measures are only just being implemented, therefore it is not yet possible to determine trends in eco-efficiency reporting. In general, firms appear to be working to improve the efficiency of their goods and service delivery. This is an important trend as it indicates the growing ability of firms to increase the quantity/number of goods and services produced for the same or a lesser quantity of resources per unit of output.

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.

Comments from the author(s)

By repeating this evaluation at a regular interval (i.e. every two or four 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.

Acknowledgments
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Contributors: Christina Forst, Oak Ridge Institute for Science and Education, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office; and Dale Phenicie & George Kuper, Council of Great Lakes Industries.
Tom Van Camp and Nicolas Dion of Industry Canada provided several data resources.
Many of the firms surveyed in this report also contributed environmental reports and other corporate information. Chambers of commerce in many states and provinces around the Great Lakes provided employment data.

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Last Updated
State of the Great Lakes 2003

Drinking Water Quality

Indicator #4175

Overall Assessment

Status: **Good**
Trend: **Unchanging**
Rationale: **The overall quality of the finished drinking water in the Great Lakes basin can be considered good. The potential risk of human exposure to the noted chemical and/or microbiological contents, and any associated health effect, is generally low.**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

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

Ecosystem Objective

The ultimate goal of this indicator is to ensure that all drinking water provided to the residents of the Great Lakes basin is protected at its source and treated in such a way that it is safe to drink without reservations. The treated water should be free from harmful chemical and microbiological contaminants. This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin ecosystem (Annex 1, 2, 12, and 16 GLWQA).

State of the Ecosystem

Background

The information provided by the United States for this report focuses mainly on finished, or treated, drinking water. This format was chosen as the focus for U.S. reporting in order to adapt to the recommendations of the *Environmental Public Health Indicators Project* (Centers for Disease Control and Prevention 2006). Additionally, the United States is in the process of establishing an inclusive national drinking water database which will include raw (source) water data, thus providing an extensive array of information to all Water Treatment Plants (WTPs), Drinking Water Systems (DWSs), researchers, and the general public. The information provided by Canada focuses on both finished and raw water.

In the United States, the Safe-Drinking Water Act Reauthorization of 1996 requires all drinking water utilities to provide yearly water quality information to their consumers. To satisfy this obligation, U.S. WTPs produce an annual Consumer Confidence/Water Quality Report (CC/WQR). These reports provide information regarding source water type (i.e., lake, river or groundwater), the availability of a source water assessment and a brief summary of the DWS's susceptibility to potential sources of contamination, the water treatment process, contaminants detected in the finished water, any violations that occurred, and other relevant information. For this indicator report the CC/WQRs were collected from 43 WTPs (Fig. 1) for the operational year 2007 (2006 when available). Furthermore, the U.S.- based Safe Drinking Water Information System (SDWIS) was also used as a means to verify information presented in the reports and to provide any other relevant information when CC/WQRs were not available.

The data used for the Canadian component of the report were provided by the Ontario Ministry of the Environment (OMOE) and included results from two program areas. Data collected as part of the Drinking Water Surveillance Program (DWSP) were provided for the period 2003-2004 (D. Fellowes, Personal Communication, OMOE 2004). 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 OMOE with their drinking water quality data. Data from January to June 2004, collected as part of this regulatory framework from 74 DWSs (Fig. 1), were also provided for analysis.

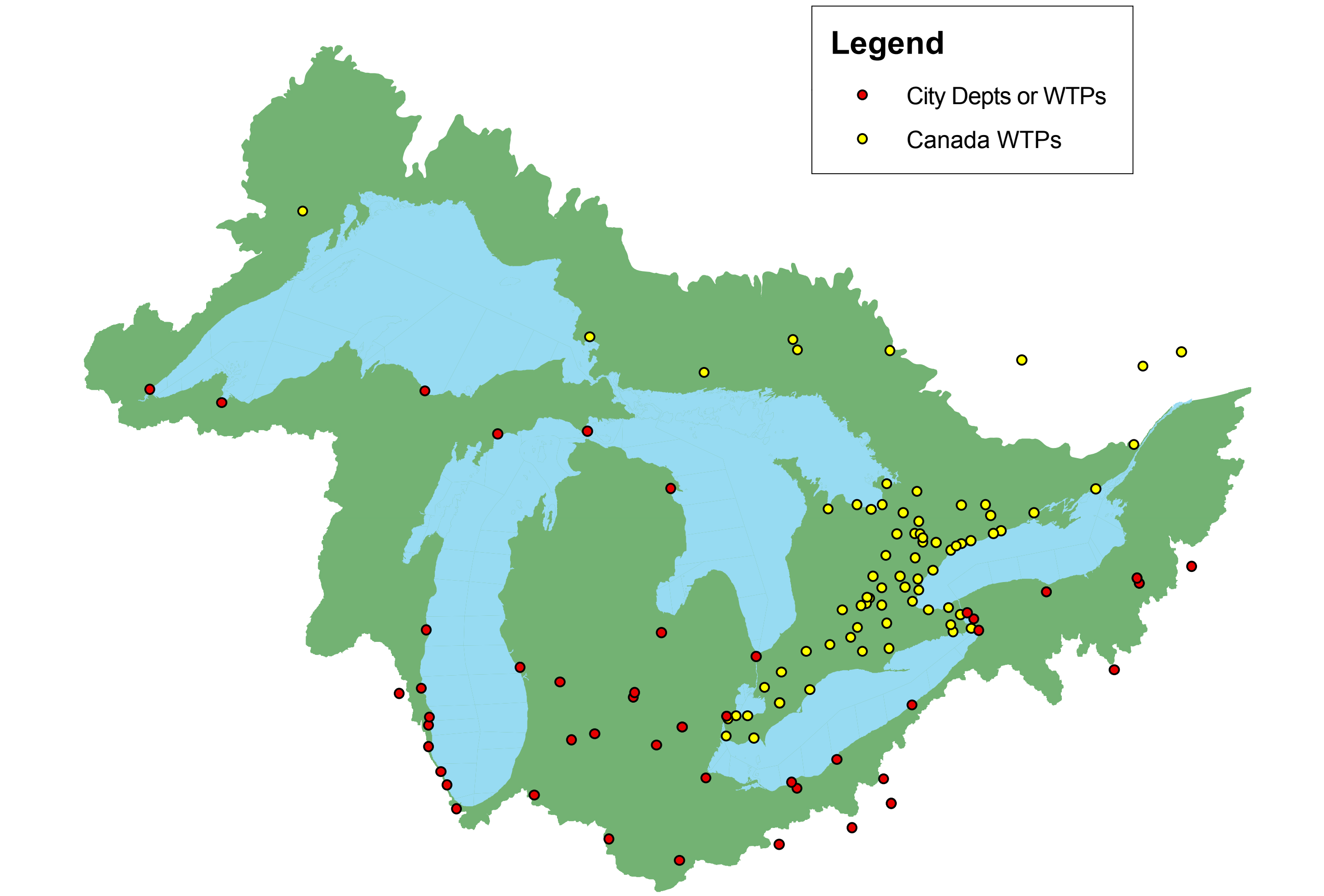

Figure 1. Location of municipalities served by U.S. and Canadian Drinking Water Systems.
Source: U.S. Environmental Protection Agency and Environment Canada.

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

Status of Drinking Water in the Great Lakes Basin

Ten drinking water parameters were chosen to provide the best assessment of drinking water quality in the Great Lakes basin. They include several chemical parameters, microbiological parameters, and other indicators of potential health hazards. These parameters are regulated by an established standard, which, when exceeded, has the potential to have serious affects on human health. The U.S. Environmental Protection Agency (U.S. EPA) defines this regulated standard as the Maximum Contaminant Level (MCL), or the highest level of a contaminant that is allowed in drinking water. The Ontario drinking water standards are described by the Maximum Acceptable Concentration (MAC), which is established for parameters that, when present above a certain concentration, have known or suspected health effects, and the Interim Maximum Acceptable Concentration (IMAC), which is established for parameters either when there is insufficient toxicological data to establish a MAC with reasonable certainty, or when it is not feasible, for practical reasons, to establish a MAC at the desired level (OMOE 2006).

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

Atrazine: This widely used, organic herbicide can enter source water though agricultural runoff and wastewater from manufacturing facilities. Consumption of drinking water that contains atrazine in excess of the regulated standard for extended periods of time can potentially lead to health complications. The U.S. EPA has set the MCL for atrazine at three ppb and the Ontario drinking water standards specify the IMAC to be five ppb, which is the lowest level at which WTPs/DWSs could reasonably be required to remove this contaminant given the present technology and resources.

In the United States, atrazine was infrequently detected in finished water supplies. When detected, it was found at levels that did not exceed the MCL. There were no health based violations or monitoring and reporting violations for any WTPs. As indicated by the annual CC/WQRs, there is a low risk of human exposure to atrazine from drinking water.

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

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

In the United States, there were two monitoring and reporting violations for nitrate. The two violations occurred between January 2006 and December 2006. However, it was never found at levels that exceeded the MCL. While there is some risk of exposure to nitrate, it is not likely to lead to serious health complications.

In Ontario, over 90% of the water samples contained nitrates. However, the highest level detected was 9.11 ppm, from a ground water sample. There is a risk of exposure to nitrates, especially in agricultural areas, but it is not likely to cause health complications because detected levels never exceeded the Ontario contamination standard.

In the United States, there is only a small potential for human exposure to nitrite from drinking water. No MCL or monitoring regulation violations were reported for nitrites.

Over 50% of the water samples contained a measurable amount of nitrite according to the Ontario drinking water system reports. However, the highest value for this contaminant only reached 0.365 ppm, which is lower than both the Ontario MAC and the highest value detected in the previous year (0.434 ppm).

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

Total Coliform: Coliforms are a broad class of bacteria that are ubiquitous in the environment and in the feces of humans and animals. The U.S. EPA has set an MCL for total coliform at 5% of the total monthly samples, but for water systems that collect fewer than 40 routine samples per month, no more than one sample per month can be positive for total coliforms. Ontario has set a MAC of zero colony forming units (cfu) for DWSs. Both Ontario and the United States require additional analysis of positive total coliform samples to determine if specific types of coliform, such as fecal coliform or *E. coli*, are present.

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

In the United States, there was only one monitoring and reporting violation for *E. coli* which occurred in March 2007. No WTPs in the United States had any health based violations for *E. coli*. However, two WTPs had health based violations for total coliform bacteria. These occurred in September and July 2006. There were also two monitoring and reporting violations for total coliform bacteria which occurred in July 2007 and in September 2007. Although there is a potential for exposure to total coliform, it is not likely to be a human health hazard in itself. However, the presence of coliform bacteria, especially at levels exceeding the MCL, indicates the possibility that microbial pathogens may be present, and this can be hazardous to human health.

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

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

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

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

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

<u>Turbidity</u>: Turbidity is a measure of the cloudiness of water and can be used to indicate water quality and filtration efficiency. Higher turbidity levels, which can inhibit the effectiveness of the disinfection/filtration process and/or provide a medium for microbial growth, are associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. A significant relationship has been demonstrated between increased turbidity and the number of *Giardia* cysts and *Cryptosporidium* oocysts breaking through filters. U.S. EPA's surface water treatment rules require WTPs using surface water, or ground water under the direct influence of surface water, to disinfect and filter their water. The rule allows systems to avoid installing filtration treatment if they can meet avoidance criteria. However, some states are more stringent, and did not adopt the filtration treatment avoidance criteria. In the United States, turbidity levels must not exceed five Nephelolometric Turbidity Units (NTU) at any time. WTPs that filter must ensure that the turbidity go no higher than one NTU and must not exceed 0.3 NTU in 95% of daily samples in any month or one NTU in 95% of daily samples in any month depending on the type of filtration treatment used. Ontario has set the aesthetic objective for turbidity at five NTU, at which point turbidity becomes visible to the naked eye.

In the United States, turbidity data are difficult to assess due to the different requirements and regulations for WTPs depending on the source water and treatment technique used. There were no health based violations, but there were two monitoring and reporting violations which occurred in June and July of 2007..

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

Total Organic Carbon: Although the presence of total organic carbon (TOC) in water does not directly imply a health hazard, the organic carbon can react with chemical disinfectants to form harmful byproducts. WTPs remove TOC from the water by using treatment techniques such as enhanced coagulation or enhanced softening. Conventional WTPs with excess TOC in the raw water are required to remove a certain percentage of the TOC depending upon the TOC amount and the alkalinity level of the raw water. The U.S. EPA only had one monitoring and reporting violation for TOC which occurred in January 2007 and it continued through March 2007. TOC data was difficult to assess due to the varying formats of CC/WQRs and the way data were presented. As such, it was difficult to quantitatively evaluate and compare the TOC levels reported by each WTP.

Dissolved Organic Carbon: Dissolved organic carbon (DOC) can indicate the potential for water deterioration during storage and distribution. Acting as a growth nutrient, increased levels of carbon can aid in the proliferation of biofilm, i.e., microbial cells that attach to the surface of pipes and multiply to form a layer of film or slime which can harbor and protect coliform bacteria from disinfectants. High DOC levels can also indicate the potential for problems from the formation of chlorination by-products. 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 five ppm.

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

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

In the United States, there were no reports of offensive taste or odors associated with the finished drinking water as indicated by the 2007 CC/WQRs.

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

Summary

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

Pressures

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

Management Implications

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

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

Comments from the author(s)

A concern for future efforts would be the adherence of a consistent guideline for identifying usable data while also providing adequate geographical coverage. In the United States, data from WTPs serving a population of 50,000 or great was used, while data from all DWSs in Ontario serving a population of 10,000 or greater was analyzed. Furthermore, focusing on this criterion for DWSs only provides a fragmented view of the drinking water patterns in the Great Lakes basin. By sporadically including additional DWSs to expand the geographical coverage area, biased results may be introduced.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

Acknowledgments

Authors:

Danielle J. Sass, Oak Ridge Institute of Science and Education (ORISE) Research Fellow, Appointed to the U.S. Environmental Protection Agency (U.S. EPA), Great Lakes National Program Office (GLNPO) 2008

Jeffrey C. May, Oak Ridge Institute for Science and Education, on assignment to U.S. Environmental Protection Agency, Chicago, IL 2006

Tracie Greenberg, Environment Canada, Burlington, ON 2006

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Consumer Confidence Reports

Akron Public Utilities Bureau – Annual Drinking Water Quality Report for 2007
Alpena Water Treatment Plant – 2007 Annual Drinking Water Quality Report
Buffalo Water Authority – 2007-2008 Annual Water Quality Report
City of Ann Arbor Water Utilities – 2006 Annual Report on Drinking Water
City of Battle Creek Public Works – 2007 Annual Water Quality Report
City of Cleveland Division of Water – 2007 Water Quality Report
City of Evanston – 2007 Water Quality Report
City of Kalamazoo – 2007 Water Quality Report
City of Kenosha Water Utility – 2007 Annual Drinking Water Quality Report
City of Mansfield – Water Quality Report 2007
City of Marquette Water Filtration Plant – 2007 Annual Drinking Water Quality Report
City of Muskegon Water Filtration Plant – 2007 Annual Water Quality Report
City of Rochester – Water Quality Report 2005
City of Sheboygan Water Utilities – 2007 Tap Water Quality Analysis
City of Syracuse Department of Water – Annual Drinking Water Quality Report for 2007

City of Toledo Water Treatment Plant – 2007 Drinking Water Quality Report
City of Waukegan – 2007 Water Quality Report
Department of Utilities Appleton Water Treatment Facility – 2007 Annual Water Quality Report to our Community
Detroit Water & Sewer Department – 2007 Water Quality Report
Elmira Water Board – Annual Drinking Water Quality Report 2007
Elyria Water Department – 2007 Annual Water Quality Report
Erie County Water Authority – 2007 Water Quality Report
Erie Water Works (EWW) – Water Quality Report for Year 2007
Fort Wayne City Utilities – 2007 Annual Drinking Water Quality Report
Green Bay Water Utility – 2007 Annual Drinking Water Quality Report
Hammond Water Works Department – 2006 Annual Drinking Water Quality Report
Lansing Board of Water & Light – 2007 Annual Water Quality Report
Lima Water Treatment Plant – 2007 Drinking Water Quality Consumer Confidence Report
Niagara Falls Water Board – Annual Drinking Water Quality Report for 2007
Milwaukee Water Works – Safe Drinking Water Report 2007
Mohawk Valley Water Authority – 2007 Water Quality Report
Monroe County Water Authority (MCWA) – 2007 Annual Water Quality Report
Onondaga County Water Authority (OCWA) – 2006 Consumer Confidence Report & Annual Water Supply Statement
Oswego City – 2007 Consumer Water Quality Report
Port Huron Water Treatment Plant – 2007 Annual Drinking Water Quality Report

Racine Water Utilities – Drinking Water Quality Report 2007
Saginaw Water Treatment Plant – Drinking Water Quality Report for 2007
South Bend Water Works – Water Quality Report 2007
The City of Chicago – Water 2007 Quality Report
Town of Tonawanda Water System – Annual Drinking Water Quality Report for 2007
Waterford Township – 2007 Annual Water Quality Report
Waukesha Water Utility – 2007 Consumer Confidence Report

Last Updated
State of the Great Lakes 2009

Biological Markers of Human Exposure to Persistent Chemicals

Indicator #4177

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **At present, no routine Great Lakes human biomonitoring programs exist to monitor biological markers of human exposure to persistent chemicals. Individual epidemiological studies have been conducted or are ongoing in the Great Lakes to monitor specific populations. For this reason, the overall status and trends are both undetermined.**

Lake-by-Lake Assessment

Individual lake assessments can not be determined for this indicator. Instead, a list of ongoing research funded by the Agency for Toxic Substances and Disease Registry (ATSDR), through its Great Lakes Human Health Effects Research Program, is provided according to the institution conducting the research.

Lake Superior

Status: Not Assessed
Trend: Undetermined
Rationale: No studies funded by ATSDR are currently being conducted by any institution in the Lake Superior basin. However, basin-wide studies do incorporate Lake Superior information.

Lake Michigan

Status: Not Assessed
Trend: Undetermined
Rationale: *Health Effects of PCB Exposure from Contaminated Fish* (Susan L. Schantz, Ph.D., University of Illinois at Urbana-Champaign);
Organo-chlorides and Sex Steroids in two Michigan Cohorts (Janet Osuch, M.D., Michigan State University);
A Pilot Program to Educate Vulnerable Populations about Fish Advisories in Upper Peninsula of Michigan (Rick Haverkate, M.P.H., Inter-Tribal Council of Michigan, Inc.).

Lake Huron

Status: Not Assessed
Trend: Undetermined
Rationale: No studies funded by ATSDR are currently being conducted by any institution in the Lake Huron basin. However, basin-wide studies do incorporate Lake Huron information.

Lake Erie

Status: Not Assessed
Trend: Undetermined
Rationale: No studies funded by ATSDR are currently being conducted by any institution in the Lake Erie basin. However, basin-wide studies do incorporate Lake Erie information.

Lake Ontario

Status: Not Assessed
Trend: Undetermined
Rationale: *Neuropsychological and Thyroid Effects of PDBEs* (Edward Fitzgerald, Ph.D., State University of New York at Albany);
PCB Congener and Metabolite Patterns in Adult Mohawks: Biomarkers of Exposure and Individual Toxicokinetics (Anthony DeCaprio, Ph.D., State University of New York at Albany);
Neurobehavioral Effects of Environmental Toxics - Oswego Children's Study: Prenatal PCB Exposure and Cognitive Development (Paul Stewart, Ph.D., State University of New York at Oswego).

Purpose

- To assess the levels of persistent toxic substances such as methyl mercury, polychlorinated biphenyls (PCBs), and dichlorodiphenyl dichloroethenes (DDEs) in the human tissue of citizens of the Great Lakes basin
- 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) (United States and Canada 1987).

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 (Anderson 2004). 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 to 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.

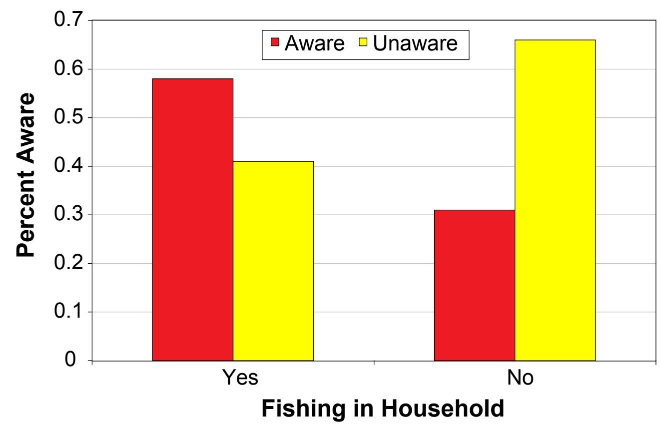

Figure 1. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories and who do (yes) or do not (no) have someone in the household who fishes.
Source: Wisconsin Department of Health and Family Services.

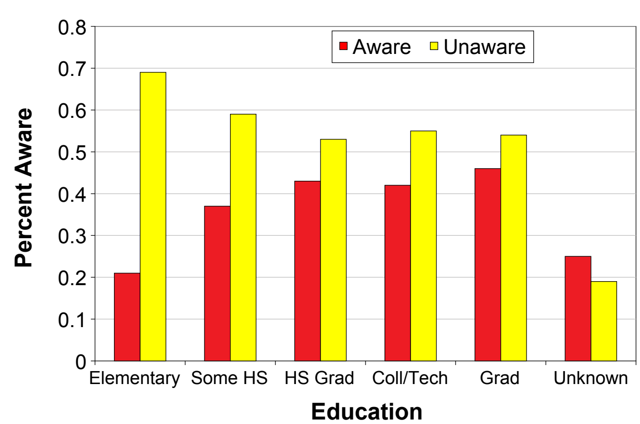

Figure 2. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to level of education.
Source: Wisconsin Department of Health and Family Services.

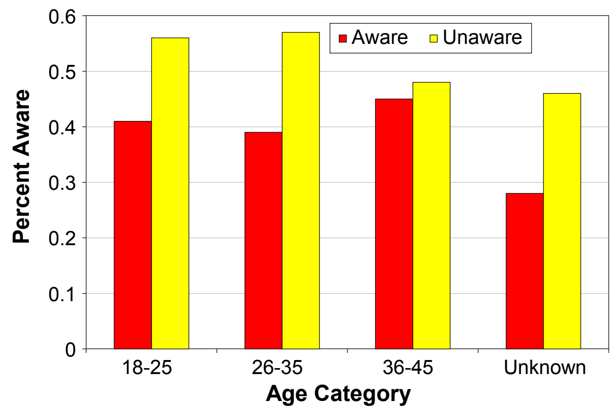

Figure 3. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to age group.
Source: Wisconsin Department of Health and Family Services.

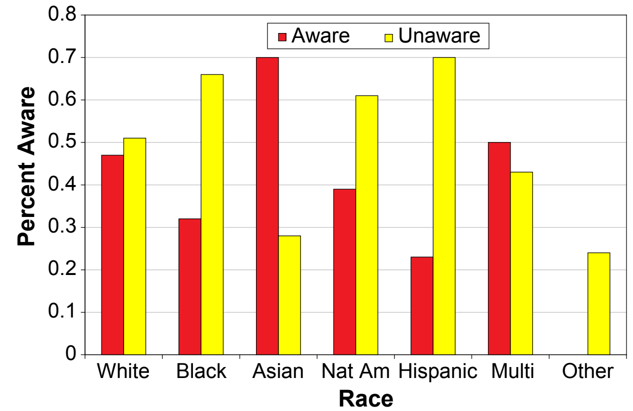

Figure 4. Percent of responders to the survey who are (red) or are not (yellow) aware of fish consumption advisories according to race.
Source: Wisconsin Department of Health and Family Services.

There was greater awareness of fish consumption advisories in households in which someone fished compared to those in which no one did (Fig. 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 (Fig. 2). More women in the 36 to 45 age category were aware of advisories than those of other ages, but there was less than 50% awareness in all age classes (Fig. 3). More Asian women were aware of advisories that those of other races, and Hispanic women were least aware of the advisories (Fig. 4).

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

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

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

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 one 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 (six to 18 fish meals) had the lowest concentration of DDE in her serum, and no PCBs were detected (Table 2).

Person ID	Fish Meals	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 (Davies and Phil 2001). The Contaminants in Human Tissues Program (CHT), a major component of the EAGLE Project, identified three main goals: to determine the levels of environmental contaminants in the tissues of First Nations people in the Great Lakes basin; to correlate these levels with freshwater fish and wild game consumption; and, to provide information and advice to First Nations people on the levels of environmental contaminants found in their tissues.

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

Key findings of the study included:

- Males consumed more fish than females and carried greater contaminant levels.
- No significant relationship was found between total fish or wild game consumption and the contaminant levels in the body.
- Levels of mercury in hair from First Nations people in the Canadian portion of the Great Lakes basin suggest the levels have decreased since 1970.
- PCBs and DDE were the most frequently appearing contaminants in the serum samples.
- Increased age of participants correlated with increased contaminant concentrations.
- Mean levels of PCBs reported in the EAGLE CHT Program were lower than or within the similar range of PCBs in fish-eaters in other Canadian health studies (Great Lakes, Lake Michigan, and St. Lawrence).
- Most people have levels of contaminants that were within Health Canada's guidelines for PCBs in serum and mercury in hair.
- Levels of DDE were similar to levels found in other Canadian health studies.
- 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 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 2006a). 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 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 (2,716) 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 between 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 (Stewart *et al*. 2003a).

Response inhibition in preschool children exposed parentally to PCBs may be due to incomplete development of their nervous system. One hundred 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*. 2003b).

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 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 two 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, little is 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 five categories of interaction profiles for toxic substances, including volatile organic compounds, metals, pesticides, and persistent contaminants found in breast milk and fish (ATSDR 2006b).

Management Implications

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

Comments from the author(s)

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

It is important that additional studies assessing the levels of bioaccumulative toxic chemicals through biomarkers be conducted on a much larger scale throughout the basin. In order to build on the WIC study, a question about fish consumption from restaurants would be important to 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 that reflect exposure, effect, and susceptibility. In addition, the program will use established cohorts to monitor changes in body burdens of persistent toxic substances and in specified health outcomes, and to develop and evaluate new health promotion strategies and risk communication tools.

Acknowledgments

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Last Updated
State of the Great Lakes 2007

Beach Advisories, Postings and Closures
Indicator #4200

Overall Assessment

Status: **Mixed**
Trend: **Unchanging**
Rationale: **The percentage of beaches open the entire season remained nearly constant in the United States (73% average) and in Canada (49% average) from 1998-2007. The percentage of beaches posted more than 10% of the season averaged 9% in the United States and 42% in Canada during 2006-2007. Differences in the percentage of open and posted beaches between the United States and Canada may reflect differing posting criteria.**

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: U.S.: Unchanging, Canada: Improving
Rationale: During 2006 and 2007, 97% or more of Lake Superior beaches were open more than 95% of the beach season in the United States. This meets the key objective of the *Great Lakes Strategy 2002* goal. In Canada, during 2006 and 2007, 79% of Lake Superior beaches were open more than 95% of the season. This does not quite meet the key objective of the *Great Lakes Strategy*, but it is an improvement from 56% the previous two years.

Lake Michigan
Status: Fair
Trend: Improving
Rationale: During 2006-2007, on average, 83% of U.S. beaches were open more than 95% of the beach season. While the key objective of the *Great Lakes Strategy 2002* has not been met, many groups continue to collaborate to identify and remediate sources of beach contamination in Lake Michigan.

Lake Huron
Status: U.S.: Good, Canada: Fair
Trend: U.S.: Unchanging, Canada: Improving
Rationale: During 2006-2007, on average, 99% of U.S. Lake Huron beaches were open more than 95% of the beach season. This meets the key objective of the *Great Lakes Strategy 2002* goal. However, in Canada, an average of 67% of Lake Huron beaches were open more than 95% of the season. This does not meet the key objective of the *Great Lakes Strategy*, but it is an improvement of 40% from the previous 2004 and 2005 data set.

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: During 2006-2007, on average, 47% of U.S. beaches were open more than 95% of the beach season. The key objective of the *Great Lakes Strategy 2002* has not been met, but efforts to identify sources of contamination are being conducted. During 2006-2007 in Ontario, an average of 32% of Lake Erie beaches were open more than 95% of the season. This does not meet the key objective of the *Great Lakes Strategy*.

Lake Ontario
Status: U.S.: Fair, Canada: Poor
Trend: U.S.: Unchanging, Canada: Deteriorating
Rationale: During 2006-2007, on average, 75% of the Lake Ontario beaches in the United States and 26% of beaches in Canada were open more than 95% of the beach season. This does not meet the key objective of the *Great Lakes Strategy 2002* and is a decrease of 12% from the 2004 and 2005 data set. Twenty three percent of U.S. beaches and 59% of Canadian beaches on Lake Ontario were posted for more than 10% of the season.

Purpose

- To assess the number of health-related swimming posting (advisories or closings) days for recreational areas (beaches) on the Great Lakes

Ecosystem Objective
Waters used for recreational activities involving body contact should be substantially free from pathogens that may harm human health, including bacteria, parasites, and viruses. As the surrogate indicator, *E. coli* levels should not exceed national, state or provincial standards set for recreational waters. This indicator supports Annexes 1, 2 and 13 of the Great Lakes Water Quality Agreement (United States and Canada 1987).

State of the Ecosystem
Background
A health-related posting day is one that is based upon elevated levels of *E. coli*, or other indicator organisms, as reported by county health departments (U.S.), Public Health Units (Ontario), or municipal health departments in the Great Lakes basin. *E. coli* and other bacterial organisms are measured in beach water samples because they act as indicators for the potential presence of pathogens which can potentially harm human health through body contact with nearshore recreational waters

The Ontario provincial standard is 100 *E. coli* colony forming units (cfu) per 100 ml, based on the geometric mean of a minimum of one sample per week from each of at least five sampling sites per beach (Ontario Ministry of Health, 1998). It is recommended by the Ontario Ministry of Health and Long-Term Care that beaches of 1000 m (0.62 mi) of length or greater require one sampling site per 200 meters (0.12 mi), with a minimum of five samples taken at each site. 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 waters are posted as unsafe for the health of bathers. Each beach in Ontario has a different swimming season length, although the average season begins in early June and continues until the first weekend in September. The difference in the swimming season length as well as the frequency of sampling may both skew the final result of the percent of beaches posted throughout the season.

The bacteria criteria recommendations for *E. coli* from the U.S. Environmental Protection Agency (U.S. EPA) are a single sample maximum value of 235 cfu per 100 ml (State of Michigan uses 300 cfu per 100 ml). For *Enterococci*, another indicator bacterium, the U.S. EPA recommended criterion is a single sample maximum value of 62 bacteria per 100 ml (U.S. EPA 1986). When levels of these indicator organisms exceed water quality standards, swimming at beaches is prohibited or advisories are issued to inform beachgoers that swimming may be unsafe. U.S. swimming seasons have varied at individual beaches. The swimming season generally starts around Memorial Day and ends around Labor Day. For consistent comparison, posting data are used only from the months of June, July and August.

The 2006-2007 Great Lakes data included significantly more U.S. beaches reporting and slightly more Canadian beaches reporting than in previous years. In the United States, the Beaches Environmental Assessment and Coastal Health (BEACH) Act amended the Clean Water Act in 2000 and required states that have coastal recreation waters, including the Great Lakes, to adopt bacteriological criteria as protective as U.S. EPA's recommended criteria (under Section 304(a) of the Clean Water Act) at their coastal waters by April 10, 2004. The BEACH Act also authorizes U.S. EPA to award grants to states, territories and eligible tribes with coastal waters to develop and implement beach monitoring and notification programs. Great Lakes beach managers are now able to regularly monitor beach water quality and advise bathers of potential risks to human health when water quality standards for bacteria are exceeded.

During an analysis of the Canadian beach dataset for 2004-2005, the authors realized that some of the reported beaches were within Public Health Units that bordered the Great Lakes but were not Great Lakes beaches, *per se*. Those beaches remain part of the Canadian datasets prior to 2004, but they were excised from the 2004-2005 data. Therefore, the applicability of trends in beach advisories prior to 2004 to just Great Lakes beaches is uncertain. Improved quality of noticeable trends in the new data set for 2006 and 2007 is apparent.

Status of Great Lakes Beach Advisories, Postings and Closures

The percentage of Great Lakes beaches open the entire season remained nearly constant in the United States during the period 1998-2007 (74% average), although the number of reporting beaches more than doubled between 2002 and 2004, and almost doubled again between 2004 and the last two years (Fig. 1). In Canada, the percentage of beaches open the entire season was far below the United States from 1998-2007 (49% average). Significantly fewer Canadian beaches were reported for the period 2004-2007 than for previous years because several non-Great Lakes beaches were included in the previous datasets (see Background above).

The percentage of beaches posted more than 10% of the beach season averaged 9% in the United States and 42% in Canada during 2006-2007. In the two reporting years prior to 2006, 12% of U.S. beaches and 54% of Canadian beaches were posted more than 10% of the season. Differences in the percentage of posted beaches between the U.S. and Canada might be due to the differing posting criteria (see Background above). Differences in the Canadian data between the periods 1998-2003 and 2004-2007 may be linked to the latter reduced dataset, but that has not been confirmed.

The U.S. *Great Lakes Strategy 2002* 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 (U.S. EPA 2006). To help meet this goal, U.S. EPA will build local capacity for monitoring, assessment and information dissemination to help beach managers and public health officials comply with U.S. EPA's *National Beach Guidance and Required Performance Criteria for Grants* (U.S. EPA 2002) at 95% of high priority coastal beaches.

A new version of the *Guideline for Canadian Recreational Water Quality* (Health Canada 1999) is expected soon, focusing on implementing measures to reduce the risk of contamination (Robertson 2006). Beach Management Programs such as Blue Flag (see Management Implications section below) will assist in improving beach water quality by performing beach surveys and creating barriers and other preventive measures for certain weather conditions to improve beach quality for the Canadian Great Lakes.

Pressures

Current pressures

Posting of beaches generally occurs a day after sampling due to the nature of the laboratory analysis; each set of beach water samples requires an average of 18 to 24 hours before the results are communicated to the beach manager. Therefore, there exists a lag time in posting beaches and in the lifting of any restrictions from the beach when bacteria levels meet water quality standards. The delay in developing a rapid test protocol for bacteriological indicators, as well as the costs, training, and collection times associated with rapid methods, is lending support to the use of predictive models to estimate when bacterial levels may exceed water quality standards.

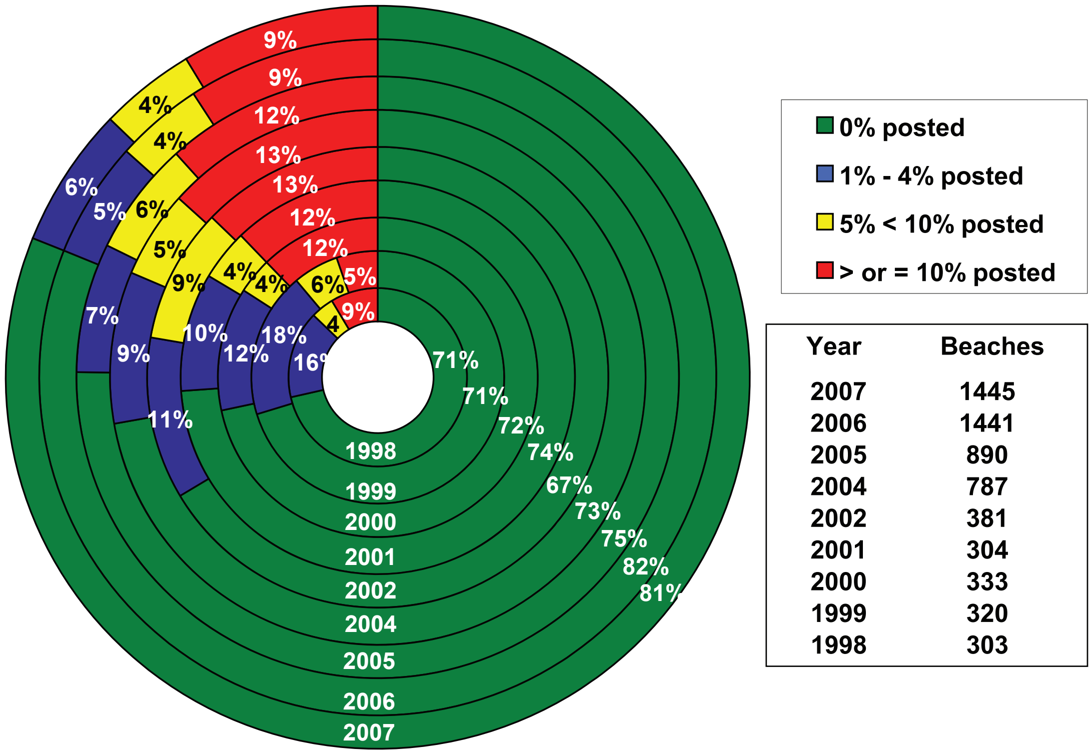
Unless contaminant sources are reduced or removed (or new contaminant sources introduced), Great Lakes beach sample results generally contain similar bacteria levels after events with similar meteorological conditions (primarily wind direction and the volume and duration of rainfall). If episodes of 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.

Future pressures

Additional point and non-point source pollution at coastal areas due to population growth and increased land use may result in additional beach postings, particularly during wet weather conditions.

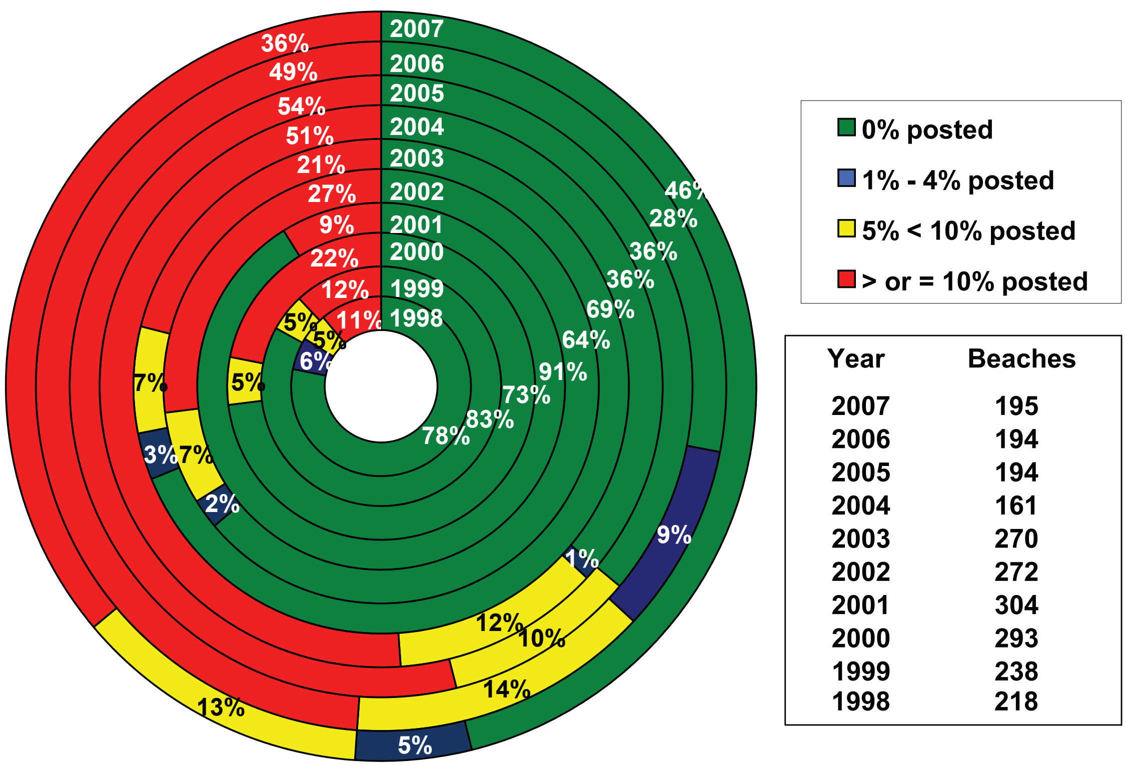
There may be new indicators and new detection methods available through current research efforts occurring binationally in both public and private sectors and academia. Although currently a concern in recreational waters, viruses and parasites are difficult to isolate and quantify, and feasible measurement techniques have yet to be developed. Comparisons of the frequency of beach

Proportion of U.S. Great Lakes Beaches with Beach Advisories for the 1998-2007 Bathing Seasons



Year	Beaches
2007	1445
2006	1441
2005	890
2004	787
2002	381
2001	304
2000	333
1999	320
1998	303

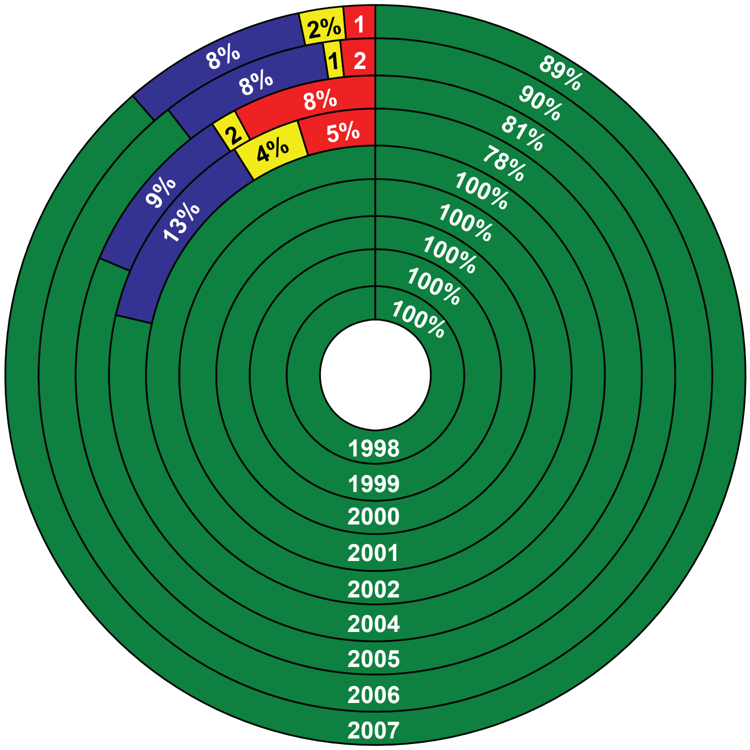
Proportion of Canadian Great Lakes Beaches with Beach Advisories for the 1998-2007 Bathing Seasons



Year	Beaches
2007	195
2006	194
2005	194
2004	161
2003	270
2002	272
2001	304
2000	293
1999	238
1998	218

Figure 1. Proportion of Great Lakes beaches with postings in the United States and Canada for the 1998-2007 bathing seasons.
Source: U.S. data compiled by U.S. EPA from Great Lakes state beach programs; Canadian data compiled by Environment Canada from Ontario Health Units.

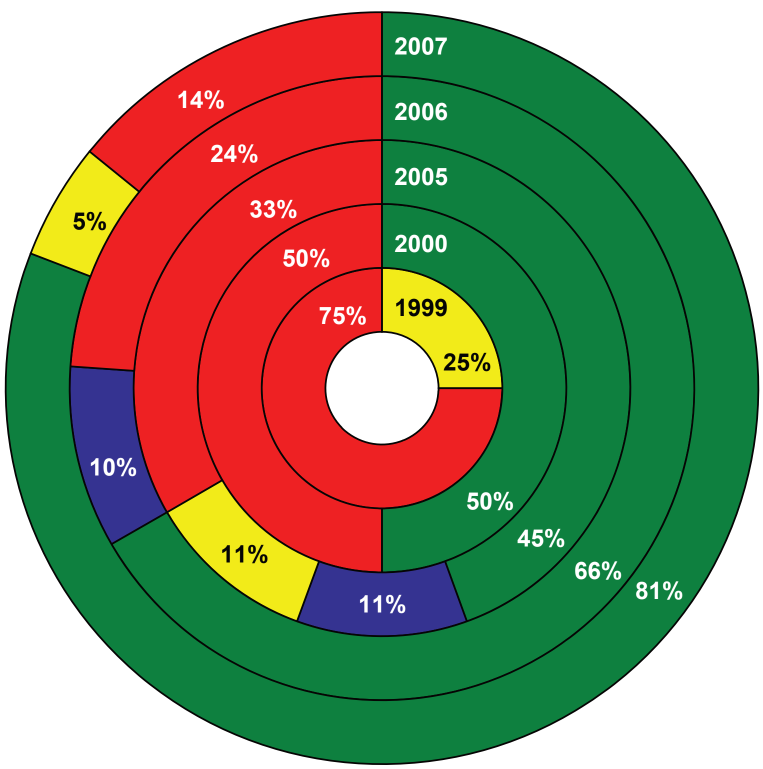
Proportion of U.S. Lake Superior Beaches with Beach Postings for the 1998-2007 Bathing Seasons



- 0% posted
- 1% - 4% posted
- 5% < 10% posted
- > or = 10% posted

Year	Beaches
2007	304
2006	305
2005	194
2004	168
2002	14
2001	10
2000	9
1999	9
1998	7

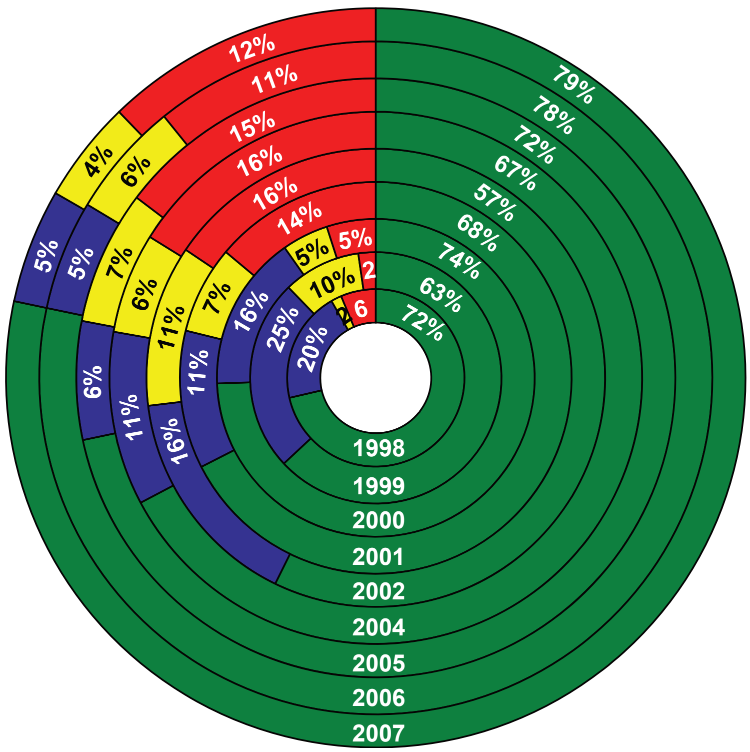
Proportion of Canadian Lake Superior Beaches with Beach Postings for the 1998-2007 Bathing Seasons



- 0% posted
- 1% - 4% posted
- 5% < 10% posted
- > or = 10% posted

Year	Beaches
2007	21
2006	21
2005	9
2004	4
2003	4

Figure 2. Proportion of Great Lakes beaches with postings for Lake Superior.
Source: U.S. data compiled by U.S. EPA from Minnesota Pollution Control Agency and Wisconsin Department of Natural Resources; Canadian data compiled by Environment Canada from Ontario Health Units.



Year	Beaches
2007	699
2006	699
2005	445
2004	427
2002	204
2001	157
2000	177
1999	173
1998	158

Figure 3. Proportion of Great Lakes beaches with postings for Lake Michigan.
Source: U.S. data compiled by U.S. EPA from Illinois Department of Public Health, Indiana Department of Environmental Management, Michigan Department of Environmental Quality, and Wisconsin Department of Natural Resources.

postings have typically been limited due to the use of different water quality criteria in different localities. In the United States, all coastal states (including those along the Great Lakes) have criteria as protective as U.S. EPA's recommended bacteriological criteria (use of *E. coli* or *Enterococci* indicators) applied to their coastal waters. Conditions required to post Ontario beaches as unsafe have become more standardized due to the 1998 Beach Management Protocol, but the conditions required to remove the postings remain variable.

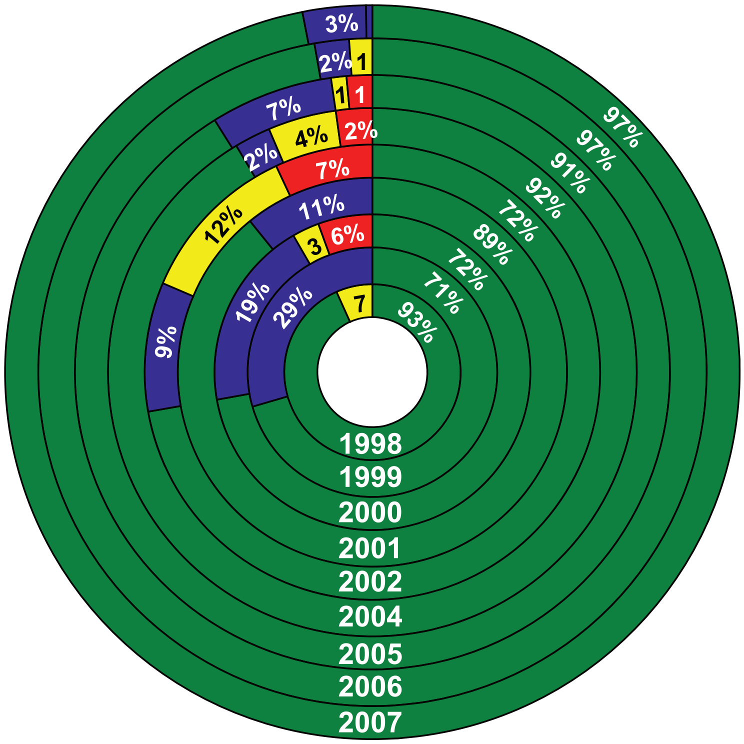
Management Implications

Recreational waters may become contaminated with animal and human feces from sources such as combined sewer overflows (CSOs), sanitary sewer overflows (SSOs), malfunctioning septic systems, and poor livestock management practices. In certain areas, these potentially harmful inputs can become exacerbated after heavy rains. States, provinces, and municipalities are continuing to identify point and non-point sources of pollution at their beaches to determine why beach areas are impaired. As some sources of contamination are identified, improved remediation measures can be taken to reduce the number of postings at beaches.

In 2007, U.S. EPA issued grants to nine entities to pilot beach sanitary surveys at 61 Great Lakes beaches in the United States and Canada. These beaches and surrounding watersheds were evaluated for existing and potential sources of pollution affecting beach water quality. Pollution sources were identified using the sanitary survey tool at all 61 beaches. Grantees also recommended remediation measures that can be taken to reduce these contamination sources. A summary of the pilot project and the sanitary survey forms can be found at: www.epa.gov/waterscience/beaches/sanitary survey/.

The Great Lakes Regional Collaboration Strategy's Coastal Health Chapter (www.glrc.us) lays out two goals: 1) to achieve a 90-95% reduction in bacterial, algal, and chemical contamination at all local beaches, and 2) at the local level, individual contamination events will occur no more than 5% of available days per bathing season, sources of these contamination events will be identified through standardized sanitary surveys, and remediation measures will be in place to address these events. Provision of funding at all levels of government for eliminating beach water contamination sources should be considered.

Proportion of U.S. Lake Huron Beaches with Beach Postings for the 1998-2007 Bathing Seasons



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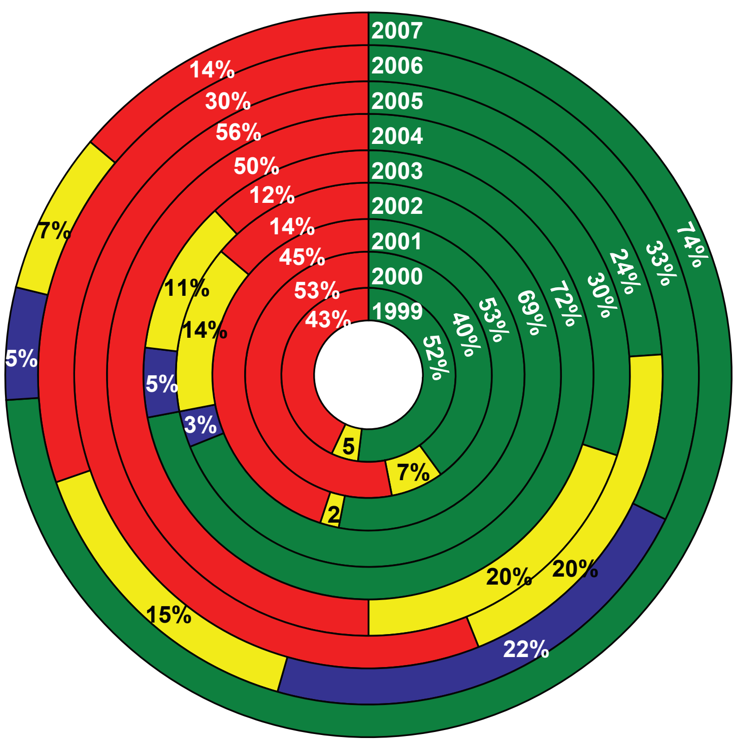
Year	Beaches
2007	286
2006	283
2005	137
2004	93
2002	43
2001	28
2000	36
1999	34
1998	30

Proportion of Canadian Lake Huron Beaches with Beach Postings for the 1998-2007 Bathing Seasons

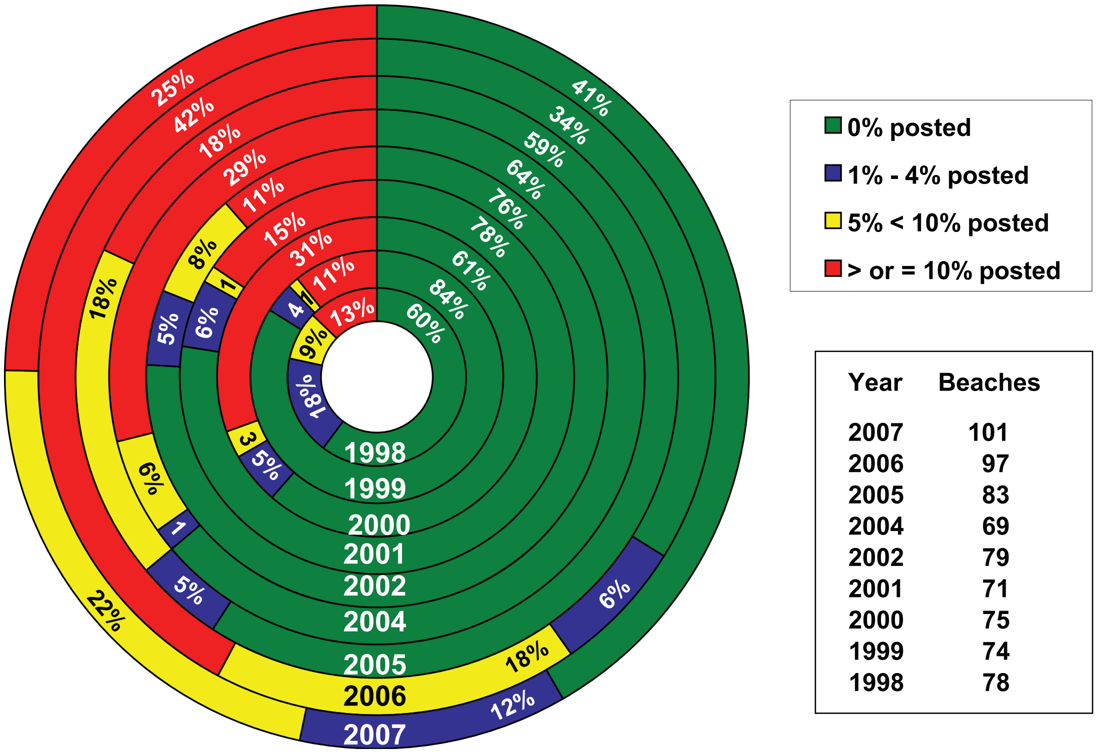


- 0% posted
- 1% - 4% posted
- 5% < 10% posted
- > or = 10% posted

Year	Beaches
2007	43
2006	59
2005	58
2004	45
2003	74
2002	75
2001	55
2000	44
1999	41

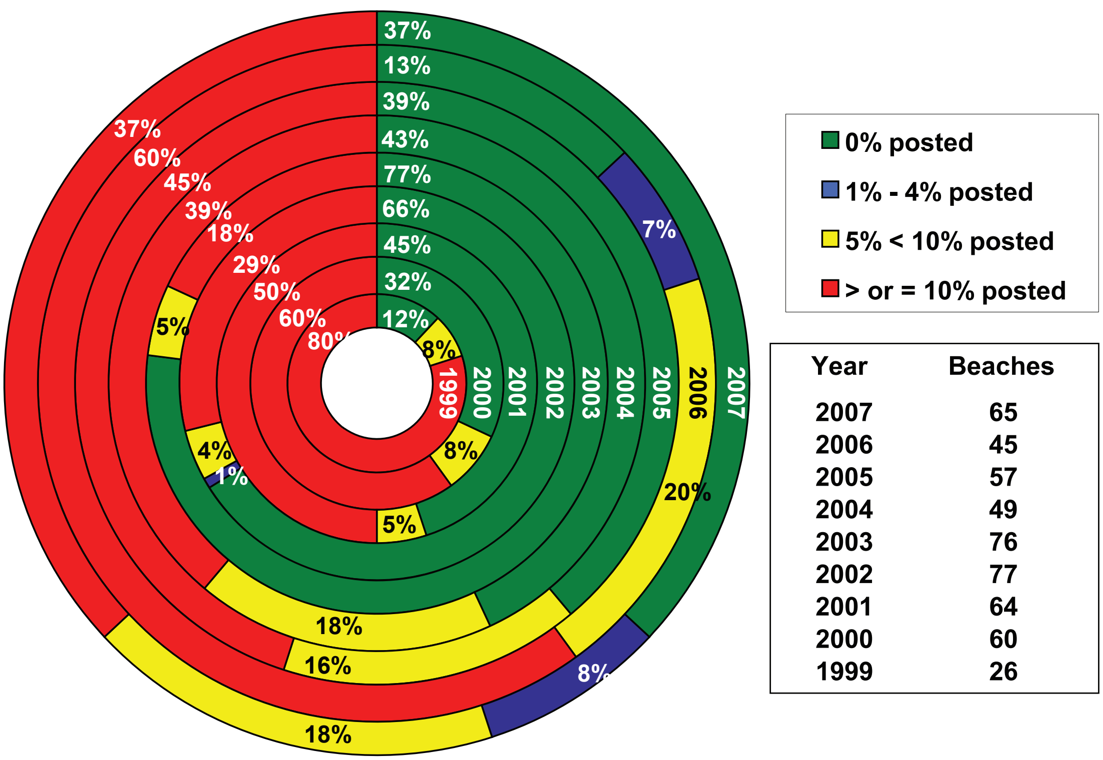
Figure 4. Proportion of Great Lakes beaches with postings for Lake Huron.
Source: U.S. data compiled by U.S. EPA from Michigan Department of Environmental Quality; Canadian data compiled by Environment Canada from Ontario Health Units.

Proportion of U.S. Lake Erie Beaches with Beach Postings for the 1998-2007 Bathing Seasons



Year	Beaches
2007	101
2006	97
2005	83
2004	69
2002	79
2001	71
2000	75
1999	74
1998	78

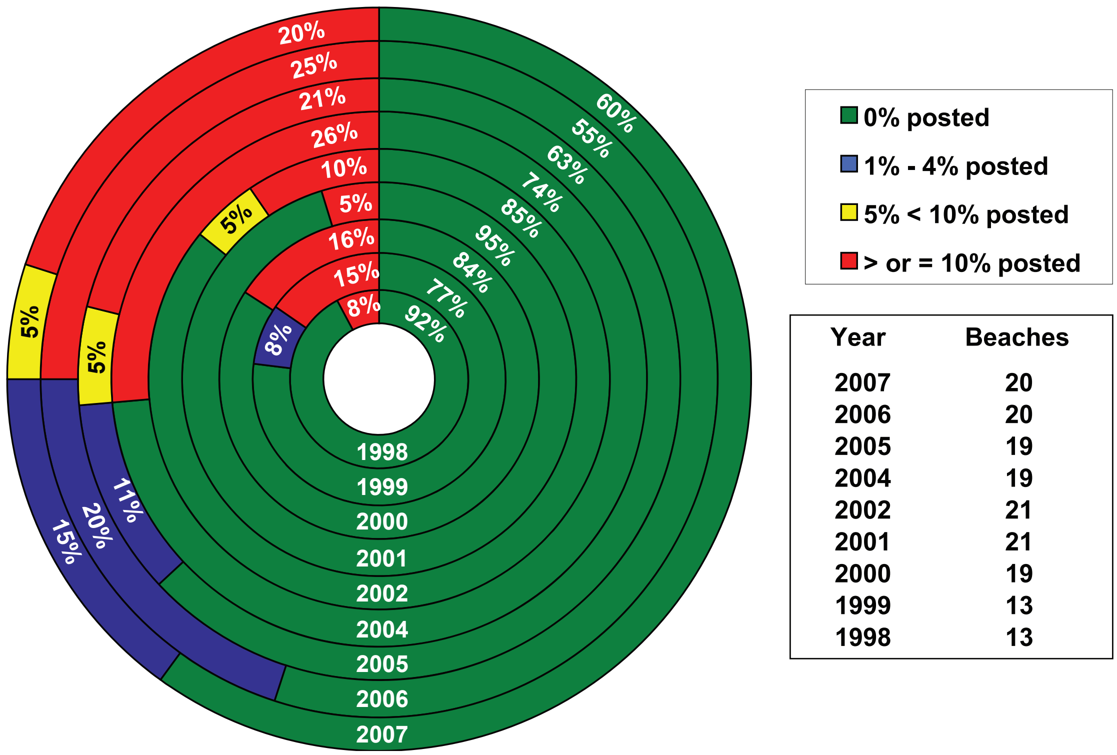
Proportion of Canadian Lake Erie Beaches with Beach Postings for the 1999-2007 Bathing Seasons



Year	Beaches
2007	65
2006	45
2005	57
2004	49
2003	76
2002	77
2001	64
2000	60
1999	26

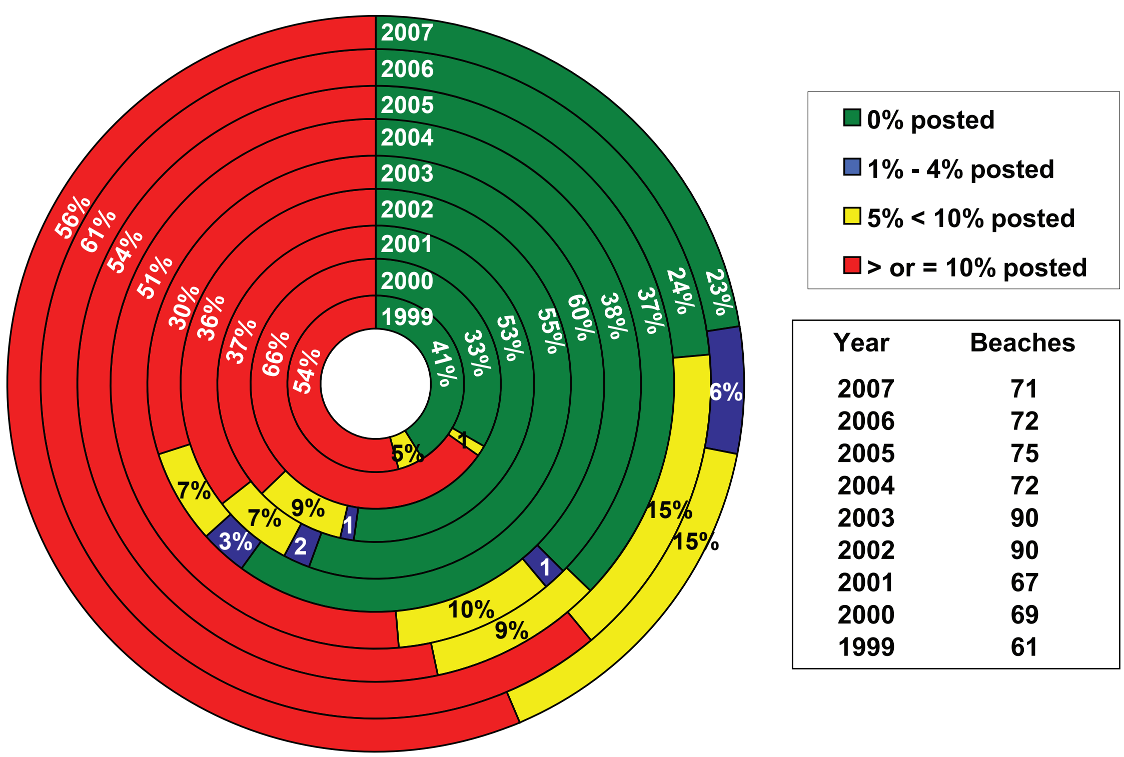
Figure 5. Proportion of Great Lakes beaches with postings for Lake Erie.
Source: U.S. data compiled by U.S. EPA from Michigan Department of Environmental Quality, Ohio Department of Health, New York State Department of Health, and Erie County, Pennsylvania, Health Department; Canadian data compiled by Environment Canada from Ontario Health Units.

Proportion of U.S. Lake Ontario Beaches with Beach Postings for the 1998-2007 Bathing Seasons



Year	Beaches
2007	20
2006	20
2005	19
2004	19
2002	21
2001	21
2000	19
1999	13
1998	13

Proportion of Canadian Lake Ontario Beaches with Beach Postings for the 1999-2007 Bathing Seasons



Year	Beaches
2007	71
2006	72
2005	75
2004	72
2003	90
2002	90
2001	67
2000	69
1999	61

Figure 6. Proportion of Great Lakes beaches with postings for Lake Ontario.
Source: U.S. data submitted by U.S. EPA from New York State Department of Health; Canadian data compiled by Environment Canada from Ontario Health Units.

Many Ontario health units are participating in beach management programs to monitor public bathing beaches and to improve public awareness. Although each health unit differs slightly, most programs participate in the same type of activities to improve recreational water quality. Some of these activities consist of assisting in enhanced beach grooming; in-water and land debris clean-up; waterfowl and gull deterrent; and public campaigns to encourage people to dispose of food scraps rather than feeding the birds which further pollutes the recreational water (City of Toronto, 2006). The Blue Flag program is becoming a well known program and an effective way of promoting clean beaches in Canada. It is an eco-label that is internationally recognized and only awarded to beaches that achieve high standards in areas such as water quality, education, environmental management and safety (Environmental Defense, 2008). In 2007, Ontario already had nine awarded Blue Flag beaches and five candidate beaches.

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. For example, 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: www.city.toronto.on.ca/wes/techservices/involved/wws/wwfmmp/index.htm.

U.S. EPA is involved in a number of activities to make the Great Lakes cleaner and safer for swimming, including working with communities to help maintain and properly operate sewage treatment plants; working to end sewage overflows in communities with outdated sewer systems; implementing a national storm water program to reduce urban runoff; and working with the Coast Guard to improve sewage disposal from recreational boats and other vessels.

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

Comments from the author(s)

Variability in the data from year to year may reflect 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 submit beach monitoring and advisory/closure data to the U.S. EPA annually. The latest beach information submitted by states can be found on U.S. EPA's BEACON (Beach Advisory and Closing On-line Notification) website at: http://oaspub.epa.gov/beacon/beacon_national_page.main. Many Ontario health units are posting beach quality information on their websites for increased public awareness.

To ensure accurate and timely posting of Great Lakes beaches, methods must be developed to deliver quicker results that focus not just on indicator organism levels but on water quality in general. This issue is being addressed. The BEACH Act requires U.S. EPA to initiate studies for use in developing appropriate and effective indicators that will improve detection of pathogens or pathogen indicators in a timely manner in coastal recreation waters. In connection with this requirement, the U.S. EPA and the Centers for Disease Control and Prevention are conducting the National Epidemiological and Environmental Assessment of Recreational (NEEAR) Water 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. Results of these studies are expected in 2010 with new or revised pathogen indicators to be published by 2012, as outlined in U.S. EPA's Critical Path Science Plan and Criteria Development Plan, which can be found at: www.epa.gov/waterscience/criteria/recreation/plan/.

On August 8, 2008, in the U.S. District Court for the Central District of California, The National Association of Clean Water Agencies (NACWA) reached a settlement with the U.S. EPA, the Natural Resources Defense Council (NRDC), and Los Angeles County in litigation involving U.S. EPA's development of new recreational water quality criteria as required by Congress in the BEACH Act.

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 by Canada and the United States. 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 indicator organism levels will likely exceed established limits in recreational waters.

In Canada, a partnership between Environment Canada (Ontario Region) and the Ontario Ministry of Health and Long-Term Care are expecting to create 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 a link to the meteorological data archives of Environment Canada. The result will be a system that can potentially have predictive modeling capability, as well as an improved 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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments
Authors: (2008)
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Sources

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U.S. beach data were obtained from U.S. EPA Program Tracking Database for Advisories, Water Quality Standards, and Nutrients (PRAWN) which were submitted by state beach program coordinators.

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Last Updated
State of the Great Lakes 2009

Contaminants in Sport Fish

Indicator #4201

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Rationale: **Concentrations of organochlorine contaminants in Great Lakes sport fish are generally decreasing. However, in the United States, PCBs still drive advisories for limiting consumption of Great Lakes sport fish. In Ontario, most of the consumption advisories are driven by PCBs, mercury, and dioxins and furans. Toxaphene also contributes to a small proportion of consumption advisories for sport fish from Lake Superior and Lake Huron (Ontario).**

Lake-by-Lake Assessment

Note: The Great Lakes Fish Monitoring Program (U.S. EPA Great Lakes National Program Office (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. Contaminant concentrations in sport fish from both GLNPO and OMOE programs determine the advised maximum consumption frequency of fish meals. OMOE calculates and issues its own advice, while GLNPO compares contaminant concentrations of collected samples (three composites of fish per site) to the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (protocol) categories (see State of the Ecosystem, Program History below). U.S. data for contaminants in sport fish cannot be used for statistical trend analysis and are not intended as public advice for consumption While it is possible that some concentrations have increased from the previous SOLEC report, this is most likely attributed to improved methods of detection and lower detection limits. Individual states and tribes issue consumption advice. Trend discussions in the lake-by-lake assessments below are based on OMOE data.

Lake Superior

Status: Mixed
Trend: Unchanging
Rationale: PCB concentrations in Lake Superior lake trout have declined considerably over the period of record. In the late 1970s, PCB concentrations significantly exceeded the current OMOE "do not eat" consumption limit of 0.844 ppm. Since 1990, concentrations have generally fluctuated between 0.105 ppm and 0.422 ppm, which would permit the consumption of two to four meals per month. In 2005, PCB concentrations increased to 0.448 ppm but declined to 0.185 ppm in 2006 (Fig. 1). PCB concentrations in GLNPO sport fish fillets currently range between the one meal per week and the one meal per month consumption advisory categories (Fig 2).

Mercury levels in walleye from Lake Superior ranged from 0.62 ppm to 0.21 ppm between 1973 and 2006, and, with the exception of a maximum level reached in 1989 (0.84 ppm), have declined over the last few decades. Since 2000, levels of mercury in walleye have been between 0.20 and 0.30 ppm, permitting the consumption of four to eight meals per month for the sensitive population (refer to Fig. 3). These mercury levels are similar to those found in fish from other Ontario lakes and rivers. Mercury concentrations in GLNPO sport fish fillets ranged between the one meal per week and 2 meals per week consumption advisories (see Fig. 4).

Toxaphene concentrations have historically been high in fish from Lake Superior due to atmospheric deposition. In lake trout, concentrations ranged from 0.810 ppm to 0.346 ppm between 1984 and 2006, with a maximum concentration exceeding 1 ppm in 1993 (Fig. 5). The most current concentrations in 60 cm lake trout permit the consumption of four meals per month. No toxaphene or DDT protocols exist to compare with concentrations found in GLNPO sport fish (see Fig. 6).

All GLNPO sport fish fillets fall into the consumption category of the draft chlordane addendum to the protocol (Fig. 7).

Lake Michigan

Status: Mixed

Trend: Improving

Rationale: GLNPO data for PCB concentrations in sport fish from Lake Michigan can be used to discern general trends due to multiple collection sites. These data display a general decline in PCB concentrations in coho and chinook salmon fillets. The majority of current concentrations fall into the one meal month consumption advice category with one site falling into the one meal per week category (Fig. 2).

Mercury concentrations in GLNPO sport fish fillets range between the one meal per week and one meal per month consumption advice categories (Fig. 4).

All GLNPO sport fish fillets fall into the unrestricted consumption category of the draft chlordane addendum to the protocol (Fig. 7).

No toxaphene or DDT protocols exist to compare with concentrations found in GLNPO sport fish (Fig. 6).

Lake Huron

Status: Mixed

Trend: Improving

Rationale: PCB levels in Lake Huron lake trout declined substantially between 1976 and 2007 (Bhavsar *et al*. 2007a). In 1976, concentrations exceeded 4 ppm, well above the "do not eat" consumption limit of 0.844 ppm for the general population. Current PCB concentrations in lake trout exceed 0.211 ppm, allowing for the safe consumption of a maximum of two meals per month. Current GLNPO data for PCB concentrations in sport fish hover around the one meal per week consumption advice category (Fig. 2).

Mercury levels in walleye from Lake Huron ranged from 0.48 ppm to 0.14 ppm between 1976 and 2007. With the exception of a maximum level reached in 1984 (0.59 ppm), there has been a general decline over the last few decades. During the last decade, levels of mercury have remained below the first level of consumption restriction (0.26 ppm) for the sensitive population (refer to Fig. 3). Mercury concentrations in GLNPO sport fish fillets fall into the one meal per week category (Fig. 4).

All GLNPO sport fish fillets fall into the unrestricted consumption category of the draft chlordane addendum to the protocol (see Fig. 7).

No toxaphene or DDT protocols exist to compare with concentrations found in GLNPO sport fish (Fig. 6).

Lake Erie

Status: Mixed

Trend: Unchanging

Rationale: Trend data are sparse for Lake Erie as lake trout are less abundant in this lake. PCB levels in lake trout declined between 1984 and 2006, however current concentrations restrict consumption to two meals per month for the general population. The sensitive population is advised not to consume these fish (Fig. 1). Current GLNPO data for PCB concentrations in sport fish fall into the one meal per month consumption advice category (Fig. 2).

Mercury levels in walleye have declined considerably, from 0.76 ppm in 1970 to 0.14 ppm in 2006. Over the past two decades, levels of mercury have remained between 0.10 and 0.20 ppm, and they do not restrict consumption of walleye (refer to Fig. 3) or lake trout. Mercury concentrations in GLNPO sport fish fall into the two meals per week category (Fig. 4).

All GLNPO sport fish fillets fall into the unrestricted consumption category of the draft chlordane addendum to the protocol (Fig. 7).

No toxaphene or DDT protocols exist to compare with concentrations found in GLNPO sport fish (Fig.6).

Lake Ontario

Status: Mixed

Trend: Improving

Rationale: Historically, the highest concentrations of PCBs in sport fish have been found in Lake Ontario. From the late 1970s to 1999, PCBs in lake trout from Lake Ontario exceeded the "do not eat" consumption limit. Substantially lower concentrations have been found in the most recent samples in 2006 and 2007, and the current levels would permit consumption of two meals per month for the general population. Current GLNPO data for PCB concentrations in sport fish fall into the one meal per week category (Fig. 2).

Annual mercury levels in walleye ranged between a minimum of 0.11 ppm and a maximum of 0.32 ppm (between 1975 and 2006), although there has been no major decline observed. Between 2003 and 2006, mercury concentrations remained below the first level of consumption restriction for the sensitive population. In 2007, mercury reached the first level of consumption restriction causing a consumption advisory of four meals per month (Fig. 3). Mercury concentrations in GLNPO sport fish also fall into the four meals per month category (Fig. 4).

High levels of mirex have been found in fish from Lake Ontario, and mirex has historically been a source of fish consumption restrictions. Levels of mirex in lake trout from Lake Ontario have declined significantly from 0.302 ppm to 0.022 ppm between 1978 and 2007, with a maximum of 0.387 ppm in 1985. The current concentration of mirex no longer restricts consumption of lake trout (Fig. 8). Photomirex is a breakdown product of mirex, which also bioaccumulates in fish and has historically caused consumption restrictions in some Lake Ontario species. Levels in lake trout have declined from 0.045 to 0.008 ppm between 1994 and 2007 (Fig. 8). There are no mirex protocols with which to compare current concentrations of GLNPO sport fish. However, Lake Ontario do display higher concentrations of mirex than the other four lakes (Fig. 9)

All GLNPO sport fish fillets fall into the unrestricted consumption category of the draft chlordane addendum to the protocol (Fig. 7).

No toxaphene or DDT protocols exist to compare with concentrations found in GLNPO sport fish (Fig. 6).

Purpose

- To assess potential human exposure to persistent bioaccumulative toxic (PBT) contaminants through consumption of popular sport fish species
- To assess the levels of PBT contaminants in Great Lakes sport fish
- 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. Unrestricted consumption of all Great Lakes sport fish should be available to all citizens of the Great Lakes basin.

State of the Ecosystem

Program History

Annex 2 of the Great Lakes Water Quality Agreement (United States and Canada 1987) requires Lakewide Management Plans (LaMPs) to define "…the threat to human health posed by critical pollutants… including their contribution to the impairment of beneficial uses." Both the *Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory* (Great Lakes Sport Fish Advisory Task Force, 1993) and the Guide to Eating Ontario Sport Fish (OMOE 2007) are used to assess the status of the ecosystem by comparing contaminant concentrations in fish to levels that invoke consumption advice. Contaminants upon which consumption advisories are based in Canada and the United States include PCBs, dioxin/furans, mercury, toxaphene, chlordane and mirex (Table 1).

Lake	Contaminants that Fish Advisories are based on in Canada and the United States
Superior	Dioxin, PCBs, toxaphene, mercury, chlordane
Huron	Dioxin, PCBs, toxaphene, mercury, chlordane
Michigan	PCBs, mercury, dioxin, chlordane
Erie	PCBs, dioxin, mercury
Ontario	PCBs, dioxin, mercury, mirex, toxaphene

Table 1. Contaminants on which the fish advisories are based on by lake for Canada and the United States.
Source: Compiled by U.S. EPA, Great Lakes National Program Office.

Both the United States and Canada (Ontario) collect and analyze sport fish to determine contaminant concentrations, to relate those concentrations to health protection values and to develop consumption advice to protect human health. The Great Lakes Fish Monitoring Program (U.S. EPA Great Lakes National Program Office (GLNPO)) and the Sport Fish Contaminant Monitoring Program (Ontario Ministry of the Environment (OMOE)) have been monitoring contaminant levels in Great Lakes fish for over three decades.

To demonstrate trends in organic contaminant levels, average-size, 60 cm (23.6 inches) lake trout (*Salvelinus namaycush*) were chosen by OMOE as the representative fish species due to their presence in all of the Great Lakes, their potential for exploitation by anglers and their high accumulation rates for organic contaminants. To demonstrate trends in mercury levels, average-size, 45 cm (17.7 inches) walleye (*Stizostedion vitreum*) were chosen by OMOE due to high mercury accumulation rates. For each of the Great Lakes, fish collected from different areas are combined into one large dataset in order to assess the entire lake. Therefore, in many cases, the contaminant levels and/or consumption advisories contained in this report (for 60 cm lake trout or 45 cm walleye) may not reflect the consumption advice for specific areas (blocks) of the Great Lakes listed in the Guide to Eating Ontario Sport Fish. Health Canada sets Tolerable Daily Intakes (TDI) for certain contaminants of concern, including PCBs, mercury, dioxins (including dioxins, furans and dioxin-like PCBs), mirex, photomirex, toxaphene and chlordane. TDIs are defined as the quantity of a chemical that can be consumed on a daily basis, for a lifetime, with reasonable assurance that one's health will not be threatened, and they are used in the calculation of sport fish consumption limits which are listed in the Guide to Eating Ontario Sport Fish. Recently, a change has been made to the PCB consumption limits used in the Guide. According to the TDI, the first advisory level begins at 0.153 ug/g for total-PCBs and 2.7 pg/g toxic equivalent (TEQ) for dioxins, furans and dioxin-like PCBs (DL-PCBs). However, based on the correlation of total-PCB with DL-PCB-TEQ (Bhavsar *et al*. 2007b) and assuming DL-PCBs contribute 100% to the TEQ (i.e., dioxins/furans in the fish are negligible in comparison), the total-PCB guideline has been adjusted to 0.105 ug/g to make it consistent with the TEQ benchmark. Therefore, in the 2007/08 Guide, a concentration of total-PCB below 0.105 ug/g is used as a benchmark for no restriction on fish consumption when DL-PCB data is not available (Table 2).

In alternating years in the United States, either coho salmon (*Oncorhynchus kisutch*) or chinook salmon (*Oncorhynchus tshawytscha*) are captured and fillets are analyzed for a suite of persistent, bioaccumulative toxic (PBT) chemicals. Steelhead trout (*Oncorhynchus mykiss*) are collected in eastern Lake Erie. The GLNPO program was not designed to determine trends in levels of contaminants in sport fish. Rather, the GLNPO program can compare yearly mean concentration levels to a set standard, the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (Table 3, Great Lakes Sport Fish Advisory Task Force 1993). The Protocol for PCBs is used as a standardized fish advisory benchmark for this indicator, and it is applied to historical 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. Due to gaps and variability in GLNPO sport fish fillet data, statistically significant trends are difficult to discern.

Advised meals per month		Concentration of PCBs (ppm)
Sensitive*	General	
8	8	< 0.153
4	4	0.153 – 0.305
Do not eat	2	0.305 – 0.610
Do not eat	1	0.610 – 1.22
Do not eat	Do not eat	>1.22

Table 2. Consumption limits used for the Guide to Eating Ontario Sport Fish (based on Health Canada TDIs).
* Women of childbearing age and children under 15.
Source: Ontario Ministry of the Environment (2008).

Advice for the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory was calculated for sensitive populations based on a weight of evidence of non-cancer developmental effects. The general population is advised to follow the same advice based on potential cancer risk. Health Canada does not consider PCBs (especially environmental levels) to be carcinogens. Therefore, non-cancer endpoints were used to calculate the Tolerable Daily Intakes (TDI) for PCBs. This TDI was applied more-or-less equally to both sensitive and general populations. For mercury, Health Canada and U.S. states assign separate TDIs or RfDs (references doses), respectively, for the general and sensitive populations, and these separate TDIs or RfDs result in different consumption limits for the general and sensitive populations (Table 2).

Consumption Advice Groups	Concentration of PCBs (ppm)	Concentration of Mercury (ppm)**	Concentration of Chlordane (ppm)***
Sensitive* and General			
Unrestricted Consumption	0 – 0.05	0<= 0.05	0 - 0.15
2 meals/ week	NA	> 0.05 <= 0.11	NA
1 meal/ week	0.06 – 0.2	> 0.11<= 0.22	0.16 - 0.65
1 meal/ month	0.21 – 1.0	> .22<= 0.95	0.66 - 2.82
6 meals/ year	1.1 – 1.9	NA	2.83 - 5.62
Do not eat	>1.9	> 0.95	> 5.62

Table 3. Uniform Great Lakes Sport Fish Consumption Advisory.
*Women of childbearing age and children under 15.
**Draft Protocol for Mercury-based Fish Consumption Advice.
***Discussion Paper for Chlordane HPV.
Source: Great Lakes Sport Fish Advisory Task Force (1993).

Other important differences between the GLNPO and OMOE programs include composited fish analysis versus individual fish analysis, skin-on versus skin-off fillets, and whole fillet analysis versus dorsal plug analysis, respectively. For this reason, only general comparisons between GLNPO and OMOE data should be made.

Contaminants in Great Lakes Sport Fish

Since the 1970s, there have been declines in the levels of many PBT chemicals in the Great Lakes basin due to bans on the use and/or production of harmful substances and restrictions on emissions. However, because of their ability to bioaccumulate and persist in the environment, PBT chemicals continue to be a significant concern. Historically, PCBs have been the contaminant that most frequently limited the consumption of Great Lakes sport fish. In some areas, dioxins/furans, toxaphene (Lake Superior) or mirex/photomirex (Lake Ontario) have been the consumption-limiting contaminants. 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/furans and decreased the relative frequency for toxaphene and mirex/photomirex.

The following figures illustrate the relationships between contaminant concentrations in sport fish and the resultant fish consumption advisories. Data and advisories are presented for: PCBs in lake trout (2005-2007) and sport fish (2005) by lake (Fig. 1 and Fig. 2); mercury in walleye (2005-2007) and sport fish (2005) by lake (Fig.3 and Fig. 4); toxaphene in lake trout from Lake Superior over time (Fig. 5); DDT in sport fish (2005) by lake (Fig. 6); chlordane in sport fish (2005) by lake (Fig. 7); mirex and photomirex in lake trout from Lake Ontario over time (Fig. 8); and mirex in sport fish (2005) by lake (Fig. 9).

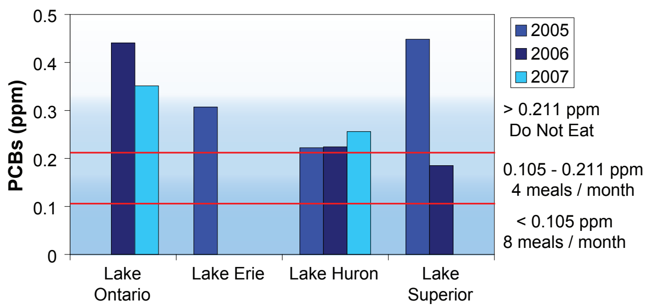


Figure 1. ΣPCBs in OMOE individual 60 cm lake trout compared to the Ontario Sport Fish Consumption Guidelines. Advisory limits for sensitive populations (women of child-bearing age and children under 15 years of age) are used in graph.
Source: Ontario Ministry of the Environment, 2008.

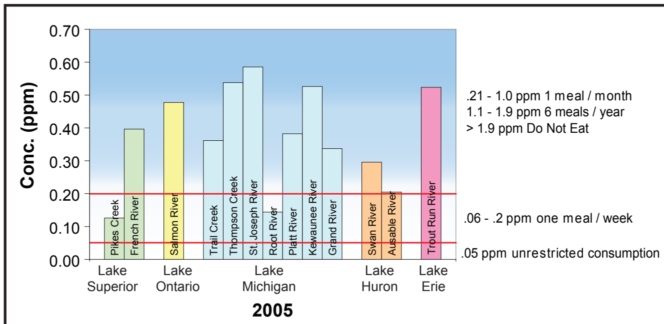


Figure 2. ΣPCBs in GLNPO sport fish fillet composites (2005) compared to the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory.
Advisory limits for sensitive populations (women of child-bearing age and children under 15 years of age) are used in graph.
Source: U.S. EPA Great Lakes National Program Office, 2008.

Pressures

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. There is a need to better understand the factors that contribute to the continuing presence of these chemicals in fish in order to determine the best course of action. 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.

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

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

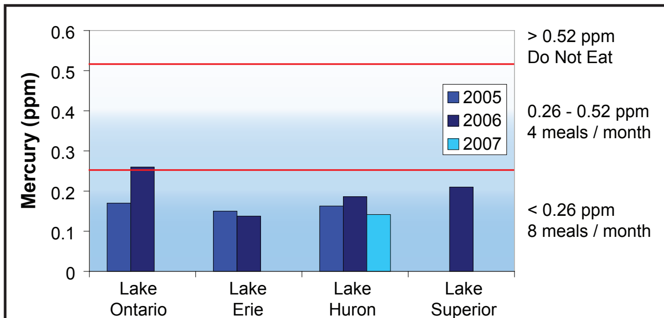


Figure 3. Mercury in OMOE individual 45 cm walleye compared to the Ontario Sport Fish Consumption Guidelines. Advisory limits for sensitive populations (women of child-bearing age and children under 15 years of age) are used in graph.
Source: Ontario Ministry of the Environment, 2008.

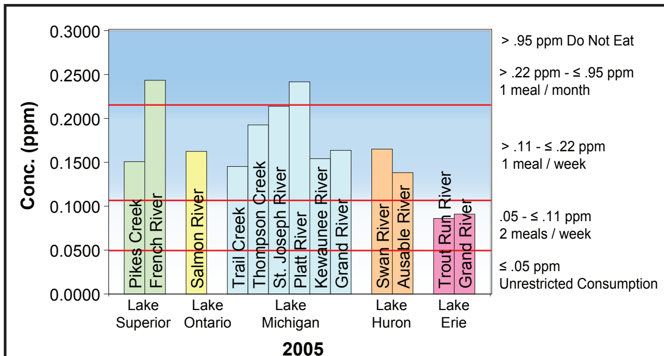


Figure 4. Mercury in GLNPO sport fish fillet composites (2005) compared to the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory.
Advisory limits for sensitive populations (women of child-bearing age and children under 15 years of age) are used in graph.
Source: U.S. EPA Great Lakes National Program Office, 2008.

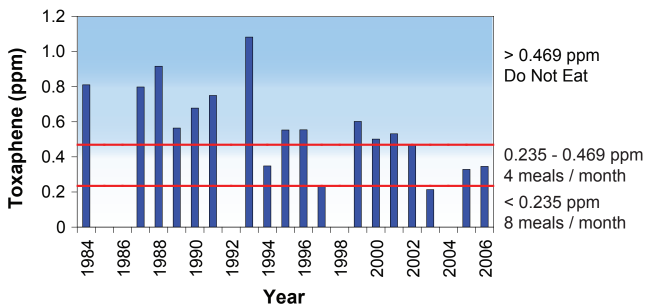


Figure 5. Toxaphene in OMOE individual 60 cm lake trout from Lake Superior compared to the Ontario Sport Fish Consumption Guidelines.
Advisory limits for sensitive populations (women of child-bearing age and children under 15 years of age) are used in graph.
Source: Ontario Ministry of the Environment, 2008.

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 U.S. EPA 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 United States Great Lakes basin, but an advisory for mercury is being drafted. There is a need to establish additional uniform PBT advisories in order to limit confusion of the public that results from issuing varying advisories for the same species of sport fish across the basin.

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

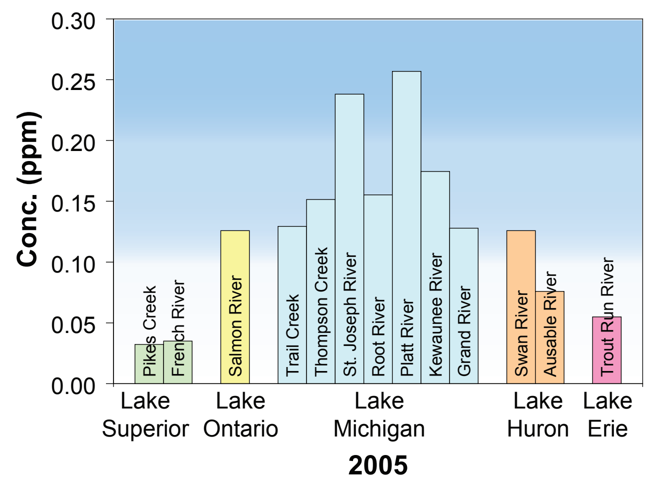


Figure 6. Total DDT in 2005 GLNPO sport fish composites - No Consumption Advice.
Coho salmon fillets in Lake Erie and Lake Michigan, and Chinook salmon fillets in Lake Huron.
Source: U.S. EPA Great Lakes National Program Office, 2008.

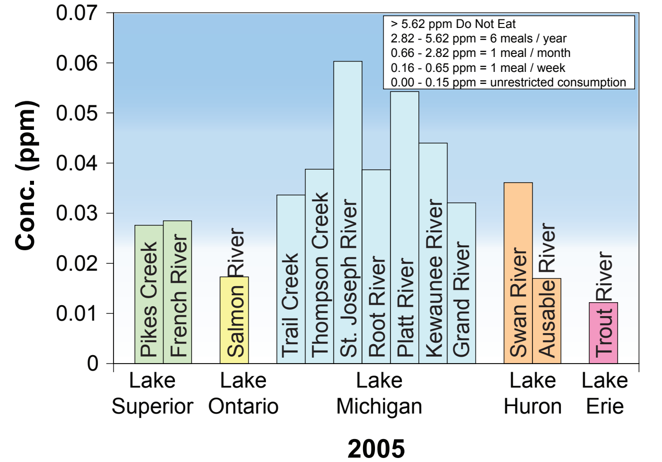
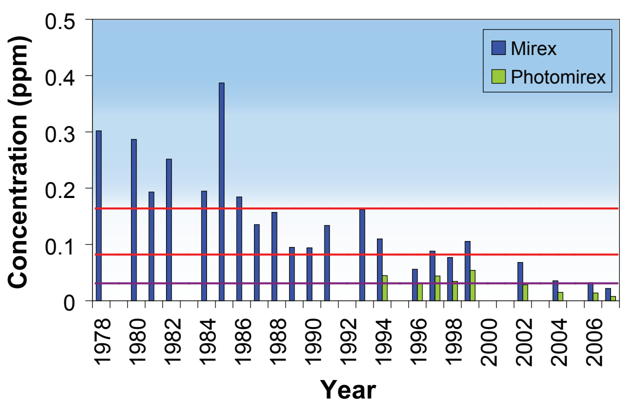


Figure 7. Total chlordane in GLNPO Chinook salmon fillet composites (2000) compared to the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory-Draft Chlordane Addendum.
Advisory limits for sensitive populations (women of child-bearing age and children under 15 years of age) are used in graph.
Source: U.S. EPA Great Lakes National Program Office, 2008.

In March, 2004, the U.S. Food and Drug Administration and the U.S. EPA 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.



Mirex:
< 0.082 ppm - 8 meals / month
0.082 - 0.164 ppm - 4 meals / month
> 0.164 ppm - Do not eat

Photomirex:
< 0.015 ppm - 8 meals / month
0.015 - 0.031 ppm - 4 meals / month
> 0.031 ppm - Do not eat

Figure 8. Mirex and photomirex in OMOE individual 60 cm lake trout compared to the Ontario Sport Fish Consumption Guidelines.
Advisory limits for sensitive populations (women of child-bearing age and children under 15 years of age) are used in graph.
Source: Ontario Ministry of the Environment, 2008.

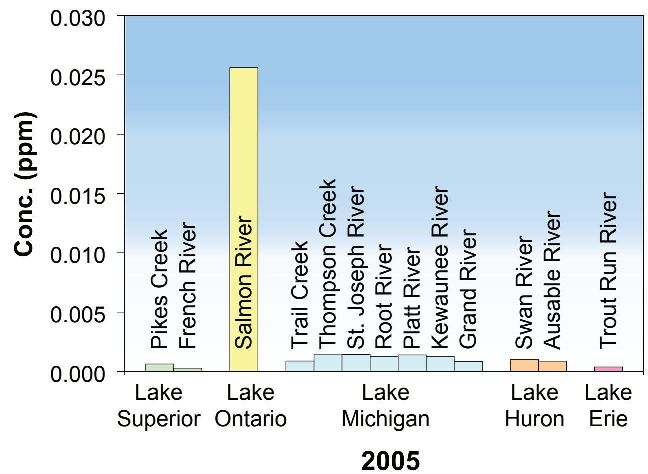


Figure 9. Mirex in GLNPO sport fish fillet composites (2005) – No consumption Advice.
Chinook salmon fillets in Lakes Superior, Michigan, Huron, and Ontario and Steelhead trout fillets in Lake Erie.
Source: U.S. EPA Great Lakes National Program Office, 2008.

Comments from the author(s)
Support is needed for the states from GLNPO and U.S. EPA headquarters to help facilitate a meeting to review risk assessment protocols.

Historical long term fish contaminant monitoring data sets, which were assembled by several jurisdictions for different purposes, need to be more effectively utilized. Relationships between the data sets need to be evaluated to 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 contaminant 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 U.S. EPA's reference dose for mercury. Ontario remains consistent with Health Canada's TDIs throughout the province.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes: In 2006, GLNPO re-competed the Great Lakes Fish Monitoring Program and identified a new principal investigator. While it is possible that some concentrations have increased from the previous SOLEC report, this is most likely attributed to improved methods of detection and lower detection limits.						

Acknowledgments
Authors: (2008)
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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.

Last Updated
State of the Great Lakes 2009

Air Quality
Indicator #4202

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Rationale: **Air quality seems to be improving on a regional scale, but localized problem areas still exist.**

Lake-by-lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose
- To monitor the air quality in the Great Lakes ecosystem
- 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 10 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, which may further contribute to the ambient levels of particulate matter.

In general, there has been significant progress with urban or 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 United States.

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 United States or Canada in this discussion refer to nationwide averages.

<u>Urban/Local Pollutants</u>
Carbon Monoxide (CO)
<u>Ambient Concentrations:</u> In the United States, the 2006 annual second highest 8-hour CO concentration averaged across 144 sites was 75% lower than that for 1980. There are currently no nonattainment areas (areas where air quality standards are not met) in the United States for CO. In general, CO levels have decreased at the same rate in the Great Lakes region as the nation as a whole (U.S. EPA 2008a).

Across Canada, the 2006 annual second highest 8-hour CO concentration averaged across 33 sites (with complete data) was 73% lower than that for 1990. In Ontario, the composite average of the 1-hour maximum CO concentration decreased by 87% from 1971 to 2006, while the composite average of the 8-hour maximum concentration decreased 92%. Ontario has not experienced an exceedence of the 1-hour (30 ppm) and 8-hour (13 ppm) criteria since 1991.

Emissions: In the United States, nationwide emissions of CO have decreased 38% from 1990 to 2006. The reductions in CO emissions are almost entirely due to decreased emissions from transportation sources, which have occurred despite yearly increases in vehicle miles traveled. In general, CO emissions have decreased at the same rate in the Great Lakes region as the nation as a whole (U.S. EPA 2006).

In Canada, anthropogenic CO emissions (not including open sources such as forest fires) have decreased nationally by about 36% between 1990 and 2006. These declines are mainly the result of more stringent transportation emission standards.

Nitrogen Dioxide (NO_2)
Ambient Concentrations: Across Canada, the 2006 annual mean NO_2 concentration was 34% lower than that for 1990. In Ontario, average NO_2 concentrations decreased by approximately 33% from 1975 to 2006. Over the last decade (1997 to 2006), average NO_2 concentrations decreased approximately 20%. The Ontario 1-hour criterion of 200 ppb and 24-hour criterion of 100 ppb for NO_2 were not exceeded at any of the monitoring locations in Ontario during 2006.

In the United States, the annual mean NO_2 concentrations decreased 41% from 1980 to 2006. NO_2 levels in the Great Lakes region decreased at a slightly higher pace during this time period. An analysis of urban versus rural monitoring sites indicates that the declining trend seen nationwide and in the Great Lakes region can mostly be attributable to decreasing concentrations of NO_2 in urban areas (similar results can be found in Ontario). There are currently no NO_2 nonattainment areas in the United States (U.S. EPA 2008).

Emissions: In Canada, anthropogenic emissions of nitrogen oxides (NO_x) (not including open sources such as forest fires) stayed essentially unchanged from 1990 to 2003, but decreased 9% between 2003 and 2006. Emissions have decreased faster in Ontario over the period from 1990 to 2006, due primarily to regulations for transportation, electricity and industrial sources.

In the United States, emissions of NO_x decreased by about 29% from 1990 to 2006. The downward trend can be attributed to emissions reductions from transportation and fuel combustion sources, which decreased by 21% and 41%, respectively. Overall, NO_x emissions did not change much between 1990 and 1998. After 1998, NO_x emissions from transportation sources decreased by 17%, and fuel combustion sources decreased by 38%. Most of the reductions at fuel combustion sources can be attributed to the U.S. EPA Acid Rain Program, which began in 1995, and implementation of the U.S. EPA NO_x State Implementation Plan (SIP) Call for Reducing Regional Transport of Ground-Level Ozone, which led to sustained NO_x reductions beginning in 2003 and 2004. Although nationwide NO_x emissions have decreased, emissions from some source categories have increased, including non-road engines. In general, NO_x emissions have decreased at a slightly greater rate in the Great Lakes region as compared to the nation as a whole (U.S. EPA 2006a).

For more information on oxides of nitrogen, refer to the *Great Lakes Indicator Report #9000 Acid Rain* (Nettesheim *et al*. 2009).

Sulfur Dioxide (SO_2)
Ambient Concentrations: In the United States, annual mean concentrations of SO_2 decreased 53% from 1990 to 2006. The Great Lakes region experienced reducing trends on par with the national averages. There are currently no nonattainment areas for SO_2 in the Great Lakes region (U.S. EPA 2006a).

Across Canada, the 2006 annual mean SO_2 concentration measured at urban stations was 54% lower than that for 1990. In Ontario, the composite annual mean for SO_2 in 2006 is 88% lower than the 1971 value. Based on relatively low concentrations over the last decade, there has been a decrease of approximately 40% in SO_2 concentrations from 1997 to 2006. In 2006, the Ontario 1-hour criterion for SO_2 of 250 ppb was exceeded at the Sudbury site for two hours; and the 24-hour criterion (100 ppb) for SO_2 was exceeded at Sarnia on two occasions. The annual criterion of 20 ppb for SO_2 was not exceeded at any site in Ontario during 2006.

Emissions: In the United States, national SO_2 emissions were reduced 38% from 1990 to 2006 mostly in response to controls implemented under the U.S. EPA Acid Rain Program, which began in 1995. Emissions from fuel combustion, industrial processes, and transportation sources decreased by 41%, 40%, and 30%, respectively. SO_2 emissions in the Great Lakes region have decreased at a much greater rate than the national trend over this time period (U.S. EPA 2006a).

Canadian SO_2 emissions decreased 38% nationwide from 1990 to 2006. Emissions (excluding natural and open sources), remained relatively stable from 1995 to 2001, but decreased 20% from 2001 to 2006. Even with increasing economic activity, emissions remain about 29% below the target national emission cap. These reductions mostly were the result of the Eastern 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, refer to the *Great Lakes Indicator Report #9000 Acid Rain* (Nettesheim *et al*. 2009).

Lead
Ambient Concentrations: U.S. concentrations of lead decreased 96% from 1980 to 2006 with most of the reductions occurring during the 1980s and early 1990s. Lead levels in the Great Lakes region decreased at nearly the same rate as the national trend over this time. There are no nonattainment areas for lead in the Great Lakes region. Large reductions in long-term lead emissions from transportation sources have changed the nature of the lead problem in the United States. Unlike the early 1980s, most of the highest lead concentrations in 2006 were near lead emissions point sources. These point sources include metals processors, battery manufacturers, waste incinerators, mining operations, military installations, and facilities with large boilers (e.g., utility, industrial, and institutional). Data for all lead monitoring sites with complete data in 2006 show lead concentrations near point sources were significantly higher than those not near point sources. The typical concentration near a source was approximately 10 times the typical concentration for sites that are not near a source (U.S. EPA 2006a, U.S. EPA 2008a).

Canadian ambient total suspended particulate matter (TSP) lead measurements began in 1974 and were phased out in 1998. For the 41 sites reporting results in this period the composite annual mean lead concentration decreased by 98% from 1974 to 1998.

Emissions: National lead emissions in the United States decreased 99% from 1970 to 2002, mostly as a result of regulatory efforts to reduce the content of lead in gasoline. Since 1990, further declines in lead emissions occurred, mostly due to reductions from on-road vehicles and non-road vehicles and engines (U.S. EPA 2008a).

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 odor problems in some communities, normally near industrial or pulp mill sources.

Emissions: Hydrogen sulfide accounts for more than half of total reduced sulfur emissions. TRS emissions only became reportable for the 2007 National Pollutant Release Inventory (NPRI). However, there has been a requirement to report hydrogen sulfide emissions since 2000. Hydrogen sulfide emissions have increased about 47% from 2000 to 2003.

PM_{10}
Ambient Concentrations: PM_{10} is the fraction of particles in the atmosphere with a diameter of 10 microns or smaller. Annual average PM_{10} concentrations (based on the second-highest 24-hour concentration at each site) in the United States have decreased 30% from 1990 to 2006. Annual average concentrations in the Great Lakes region have decreased at nearly the same rate as the national trend over this time. There are currently no nonattainment areas in the Great Lakes region (U.S. EPA 2006a).

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 to guide decision-making.

Emissions: In the United States, national primary PM_{10} emissions from anthropogenic sources decreased 20% from 1990 to 2006. Changes in how U.S. EPA compiled the national inventories in 1996 and 2002 may account for some variation. The Great Lakes region experienced reducing trends slightly higher than the national averages (U.S. EPA 2006a).

In Canada, anthropogenic PM_{10} emissions (not including open or natural sources such as road dust and forest fires) have decreased nationally by about 36% between 1990 and 2006.

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. are cancer causing) or cause 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 is usually limited in scope because such toxics are usually present only at trace levels. Recent efforts in Canada and the United States have focused on better characterization of ambient levels and minimizing emissions. In the United States, 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 tonnes (1.5 million tons) per year from 1990 levels.

In February 2006, U.S. EPA released the results of its national assessment of air toxics (NATA) using 1999 emissions. The purpose of the national-scale assessment is to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern in terms of contributing to population risk. From a national perspective, benzene is the most significant air toxic for which cancer risk could be estimated, contributing 25% of the average individual cancer risk identified in this assessment. Based on U.S. EPA's 1999 national emissions inventory, the key sources for benzene are on-road (49%) and non-road mobile sources (19%), and open burning, prescribed fires and wildfires (14%). U.S. EPA projects that on-road and non-road mobile source benzene emissions will decrease by about 60% between 1999 and 2020, as a result of motor vehicle standards, fuel controls, standards for non-road engines and equipment, and motor vehicle inspection and maintenance programs.

Of the 40 air toxics showing the potential for respiratory effects, acrolein is the most significant, contributing 91% of the nationwide average non-cancer hazard identified in this assessment. Note that the health information and exposure data for acrolein include much more uncertainty than those for benzene. Based on the 1999 national emissions inventory, the key sources for acrolein are open burning, prescribed fires and wildfires (61%), on-road (14%) and non-road (11%) mobile sources. The apparent dominance of acrolein as a non-cancer "risk driver" in both the 1996 and 1999 national-scale assessment has led to efforts to develop an effective monitoring test method for this pollutant. U.S. EPA projects acrolein emissions from on-road sources will be reduced by 53% between 1996 and 2020 as a result of existing motor vehicle standards and fuel controls.

The assessment estimates that most people have a lifetime cancer risk between one and 25 in a million from air toxics. This means that out of one million people, between one and 25 people have increased likelihood of contracting cancer as a result of breathing air toxics from outdoor sources if they were exposed to 1999 levels over the course of their lifetime. The assessment estimates that most urban locations have air toxics lifetime cancer risk greater than 25 in a million. Risk in transportation corridors and some other locations are greater than 50 in a million. In contrast, one out of every three Americans (330,000 in a million) will contract cancer during a lifetime, when all causes (including exposure to air toxics) are taken into account. Based on these results, the risk of contracting cancer is increased less than 1% due to inhalation of air toxics from outdoor sources.

In Canada, key toxics such as benzene, mercury, dioxins, and furans are the subject of ratified and proposed new standards, and voluntary reduction efforts.

Ambient Concentrations: A National Air Toxics Trend Site (NATTS) network was launched in the United States 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 (averaged across 23 urban sites) have decreased 55% in the United States from 1994 to 2006. In the Great Lakes region, most sites indicate a statistically significant decreasing trend for any five-year period from 1990 to 2005. While some sites show an increase over this time period, no site shows a statistically significant increase (Fig. 1).

Manganese compounds are hazardous air pollutants of special concern in the Great Lakes region. They are emitted by iron and steel production plants, power plants, coke ovens, and many smaller metal processing facilities. Exposures to elevated concentrations of manganese are harmful to human health and have been associated with subtle neurological effects, such as

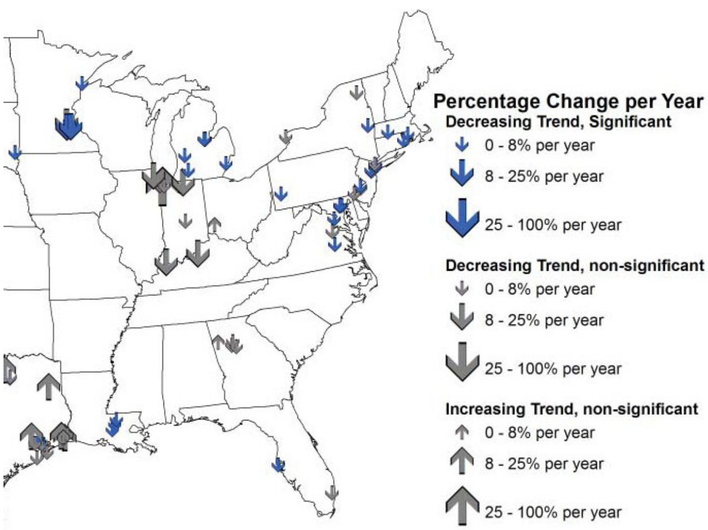

Figure 1. Trends in annual average benzene concentrations at individual sites for any period of at least five years within 1990-2005.
Source: U.S. Environmental Protection Agency (U.S. EPA) 2008b. Latest Findings on National Air Quality: Status and Trends Through 2006. January 2008. EPA-454-R-07-007. http://www.epa.gov/air/airtrends/2007/report/trends_report_full.pdf, last accessed September 18, 2008.

slowed eye-hand coordination. The most recent NATA results identify manganese compounds as the largest contributor to neurological non-cancer health risk in the United States. Modeled estimates of ambient manganese compounds in all 3222 U.S. counties show that among the 50 counties with the highest concentrations nation-wide, 20 are located in U.S. EPA's Region 5. The median average annual manganese concentration at 21 trend sites showed a 28% decline between 2000 and 2006. Additional years of data may be needed to confirm this apparent trend.

Across Canada, for the period 1991 to 2006 there were 21 urban sites in 12 cities that had complete annual data records for benzene. Urban benzene concentrations decreased by 68% between 1991 and 2006.

Emissions: The Great Lakes Regional Air Toxics Emissions Inventory is an ongoing initiative of the regulatory agencies in the eight Great Lakes states and the Province of Ontario. Emissions inventories have been developed for 1996, 1997, 1998, 1999, 2001, and 2002, but different approaches were used to develop these inventories making trend analysis difficult.

In Canada, emissions are also being tracked through the NPRI. The NPRI includes information on some of the substances listed by the Accelerated Reduction/Elimination of Toxics (ARET) program. Significant voluntary reductions in toxic emissions have been reported through the ARET program.

In the United States, emissions are also being tracked through the NEI and the Toxics Release Inventory (TRI). NEI data indicate that national U.S. air toxic emissions have dropped approximately 36%, from 6.5 million tonnes (7.2 million tons) per year in the baseline period (1990-1993) to 4.2 million tonnes (4.6 million tons) per year in 2002. This downward trend resulted primarily from reduced emissions from stationary sources and on-road mobile sources (67% and 47% reduction, respectively), while emissions from both area and non-road mobile sources increased over this period (26% and 15%, respectively). Estimated emissions decreased between the baseline period (1990-1993) and 2002 for the five compounds, believed to account for the greatest health risks that are attributed to air toxics, according to the national assessment: acrolein (51%); benzene (17%); 1,3-butadiene (38%); ethylene dibromide (63%); and hydrazine (84%). Although changes in how U.S. EPA compiled the national inventory over time may account for some differences, U.S. EPA and state regulations, as well as voluntary reductions by industry, have clearly achieved large reductions in total toxic emissions. The 1999 NEI also showed that Region 5 had the highest manganese emissions of all U.S. EPA Regions, contributing 36.6% of all manganese compounds emitted nation-wide. Manganese emissions from industrial sources in EPA Region 5 occurred from various facilities, such as those that manufacture steel or process iron ores and alloys for steel making.

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 (point and fugitive sources) of the TRI 1988 Core Chemicals (296 chemicals) in the eight Great Lakes states have decreased by about 80% from 1988 to 2006. According to the TRI, manganese emissions from point sources declined between 1988 and 2003 both nationally (26.2%) and in U.S. EPA Region 5 (36.7%). Year-to-year variability in manganese emissions is high, however, and recent emissions data (1996-2003) suggest a weaker trend: emissions dropped 7.6% and 12.4% nation-wide and in U.S. EPA Region 5, respectively.

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. Local onshore circulations around the Great Lakes can exacerbate the problem, as pollutants can remain trapped for days below a maritime/marine inversion, which 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 Lake Huron and Lake Erie, and western Michigan is impacted by transport across Lake Michigan from Chicago.

Ambient Concentrations: Between the 1978-1980 and the 2004-2006 averaging periods, nationwide fourth-highest daily maximum 8-hour ambient ozone concentrations decreased by 25%. However, the rate of decline has slowed since 1990 with only about a 9% reduction in concentrations. In 2006, ozone levels in the United States showed a continued improvement that started in 2002. The Great Lakes region (including portions of U.S. EPA's Regions 2, 3 and 5) has experienced smaller decreases than nationwide averages. Many of the improvements in ozone concentrations during these times have been a result of local emission reductions in urban areas.

To address the regional transport of ozone and ozone-forming pollutants in the eastern half of the country, the U.S. EPA developed a program to reduce regional NO_x emissions called the NO_x State Implementation Plan (SIP) Call in 2002. An analysis of ozone data in the NO_x SIP Call region shows an average reduction in seasonal 8-hour ozone concentrations of about 13% from 2002 to 2006. After adjusting for meteorology, the improvement in 8-hour ozone concentrations was about 8% (Fig. 2). While, on average, there was no net improvement in ozone concentrations in the region between 2004 and 2006, results show that the majority of the ozone progress made between 2002 and 2004 is being maintained.

Since the State of the Great Lakes 2005 indicator report, the 1-hour ozone standard was revoked in the United States and all six nonattainment areas in the Great Lakes basin were reclassified. Since the State of the Great Lakes 2007 indicator report, 16 areas covering 24 counties in the Great Lakes basin were redesignated to being in "attainment" for the 8-hour ozone standard. These areas include South Bend/Elkhart, IN; LaPorte County, IN; Fort Wayne, IN; Flint metro area, MI; Grand Rapids metro area, MI; Muskegon County, MI; Huron County, MI; Kalamazoo-Battle Creek metro area, MI; Lansing-East Lansing metro area, MI; Benton Harbor area, MI; Benzie County, MI; Cass County, MI; Mason County, MI; Toledo metro area, OH; Erie, PA; and Kewaunee County, WI. That leaves 12 areas covering 46 counties in nonattainment for the 8-hour ozone standard (Chicago-Gary-Lake Co, IL-IN metropolitan (or metro) area; Detroit-Ann Arbor metro area, MI; Allegan County, MI; Jamestown, NY; Buffalo-Niagara Falls metro area, NY; Rochester metro area, NY; Jefferson County, NY; Cleveland-Akron-Lorain metro area, OH; Milwaukee-Racine metro area, WI; Sheboygan County, WI; Manitowoc County, WI; and Door County, WI). In 2008, U.S. EPA revised its national ambient air quality standard for ground-level ozone to a level of 0.075 ppm (from 0.08 ppm). U.S. EPA will issue new designations of attainment and nonattainment by 2010 based on the revised ozone standard.

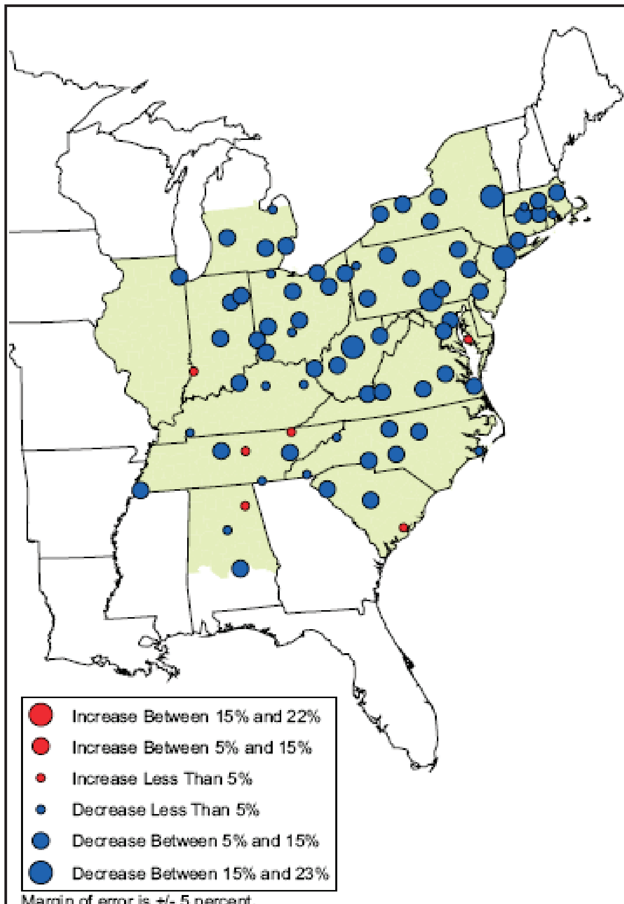

Figure 2. Percent Change in 8-hour Ozone Concentrations, 2002 versus 2006 (adjusted for meteorology).

Source: U.S. Environmental Protection Agency (U.S. EPA). 2007b. NO_x Budget Trading Program: 2006 Program Compliance and Environmental Results. EPA-430-R-07-009. http://www.epa.gov/airmarkt/progress/docs/2006-NBP-Report.pdf, last accessed September 18, 2008.

In 2006, Ontario's 1-hour ozone criterion of 80 ppb was exceeded at 35 of the 38 Air Quality Index (AQI) stations on at least one occasion. Although the ozone levels continue to exceed Ontario's criterion, there is an overall decreasing trend (15%) in the average annual 1-hour maximum ozone concentrations from 1980 to 2006. Over the past 10 years (1997 to 2006), the annual composite means of the 1-hour maximum concentrations of ozone have decreased by approximately 11% on average; most of this change has occurred over the last three years.

However, Ontario has experienced an overall increasing trend in the ozone seasonal means from 1980 to 2006. The ozone summer means have increased by approximately 27% and the winter means by approximately 50% (Fig. 3). The increases in summer and winter ozone means appear to be largely related to the reductions in NO_x emissions and the rising global background ozone concentrations.

In Ontario, ozone data from 20 designated Canada-Wide Standard (CWS) sites indicate that all but one monitoring site (Thunder Bay) exceeded the CWS target of 65 ppb based on the fourth-highest ozone 8-hour daily maximum averaged over three years (2004 to 2006).

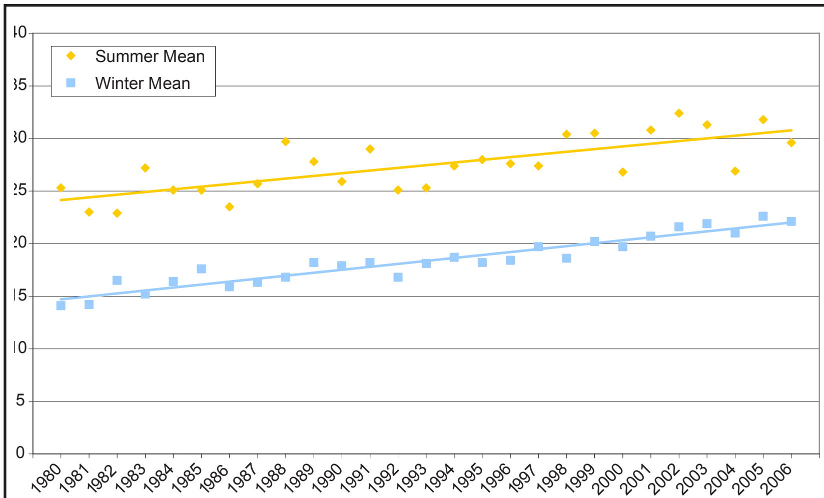

Figure 3. Trend of Ozone Seasonal Means at Sites Across Ontario (1980 - 2006).
Source: Ontario Ministry of the Environment (OMOE). 2007. Air Quality in Ontario 2006 Report. Queen's Printer for Ontario. http://www.airqualityontario.com/press/publications.cfm, last accessed August 22, 2008.

Emissions: In the United States, summer emissions of VOCs decreased by 20% from 1997 to 2006. Summer (May to September) emissions are used because ozone is mostly a summer-season pollutant. In addition, 1997 was selected as a base year because of a change in the emissions inventory methodology for VOCs in 1996. From 1996 to 2002, the rate of VOC emissions reduction in the Great Lakes basin was somewhat greater than the national average. Also in 2002, VOC emissions from biogenic sources were estimated to determine the relative contribution of natural versus anthropogenic sources. It was estimated that biogenic emissions contributed approximately 72% of all VOC emissions in the country. Summertime NO_x emissions in the United States have also decreased 30% from 1997 to 2006.

In Canada, anthropogenic VOC emissions have decreased 23% from 1990 to 2006. The reductions are mostly attributable to the transportation and petroleum refining sectors. Canadian NO_x emissions have decreased by about 8% over the same time period.

$PM_{2.5}$
This fraction of particulate matter (diameter of 2.5 microns or less) is a health concern because it can penetrate deeply into the lung, in contrast to larger particles. Although $PM_{2.5}$ is primarily a secondary pollutant produced from both natural and man-made precursors (SO_2, NO_x, VOC and ammonia), it can also be emitted directly from a source.

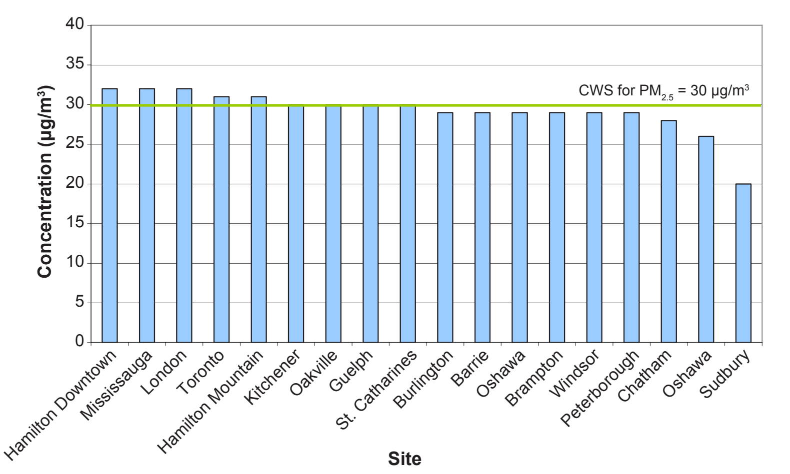

Figure 4. $PM_{2.5}$ Levels at Designated CWS Sites Across Ontario Based on the CWS for $PM_{2.5}$ (2004 - 2006).
Source: Ontario Ministry of the Environment (OMOE). 2007. Air Quality in Ontario 2006 Report. Queen's Printer for Ontario. http://www.airqualityontario.com/press/publications.cfm, last accessed August 22, 2008.

Ambient Concentrations: In Canada, a CWS for $PM_{2.5}$ of 30 µg/m^3 was established in June 2000. Achievement of the standard is based on the three-year average of the annual 98th percentiles of the daily, 24-hour (midnight to midnight) average concentrations. As continuous

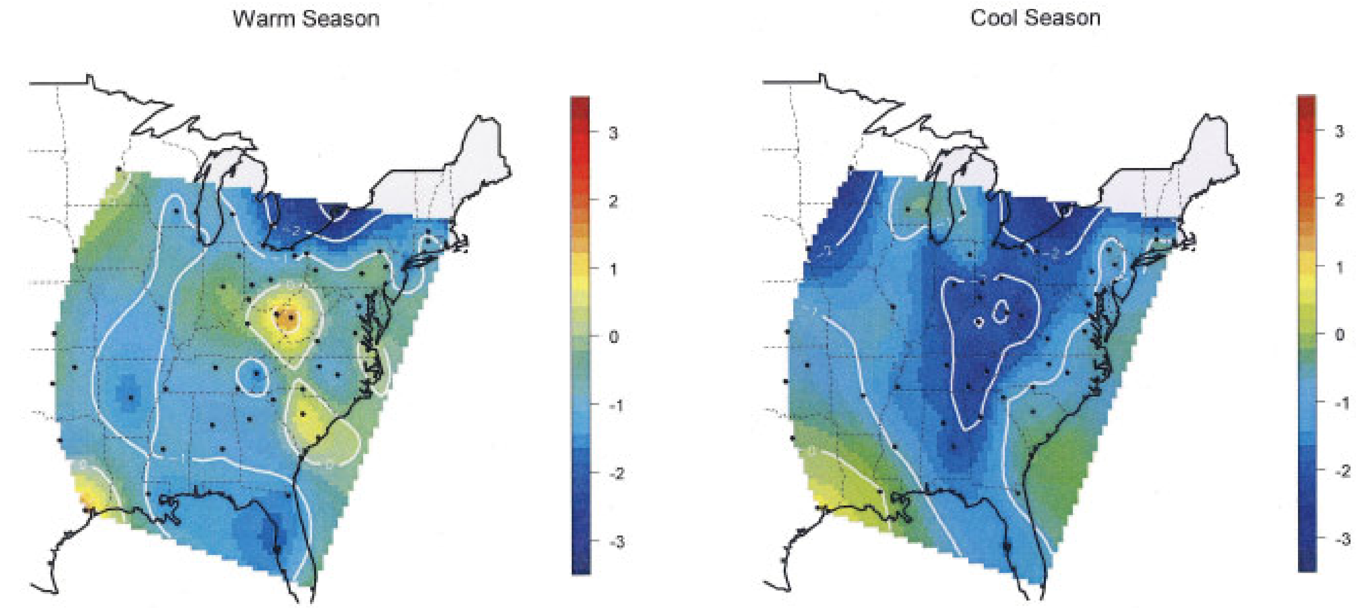

Figure 5. Change in warm (April-September) and cool season (October-March) $PM_{2.5}$ Concentrations in µg/m^3 after removing the influence of weather, 2000-2001 (average) vs 2005-2006 (average).
Source: U.S. Environmental Protection Agency (U.S. EPA). 2008b. Latest Findings on National Air Quality: Status and Trends Through 2006. January 2008. EPA-454-R-07-007. http://www.epa.gov/air/airtrends/2007/report/trends_report_full.pdf, last accessed September 18, 2008.

$PM_{2.5}$ monitoring has only begun quite recently, there are not enough data to show any national long-term trends. The composite annual mean $PM_{2.5}$ concentration from 14 dichotomous sites decreased by 40% from 1985 to 1996, increased from 1996 to 2003, and has shown a downward trend since.

In Ontario, fine particulate matter data from 2004 to 2006 indicate that five of the 18 designated sites in Ontario exceeded the CWS target of 30 µg/m^3 (Fig. 4). In Ontario, during summer episodes, $PM_{2.5}$ mainly consists of sulfate particles.

In the United States, annual average $PM_{2.5}$ concentrations have declined nationally by 14% between 2000 and 2006. Similar trends are seen for daily $PM_{2.5}$ concentrations with a 15% decline over the same period. The regional rate of decrease in the Great Lakes basin is roughly in line with the national averages. The trends are based on measurements collected at 721 monitoring stations that have sufficient data to assess trends over that period.

Weather plays an important role in the formation and emission sources of $PM_{2.5}$. For example, in colder months the greater demand for home and office heating creates more direct emissions of $PM_{2.5}$, while in warmer months, weather conditions are more conducive to $PM_{2.5}$ formation. After adjusting for weather, $PM_{2.5}$ concentrations show a more modest decrease of 11% from 2000 to 2006. Figure 5 further illustrates the changes in both warm (April-September) and cool (October-March) season $PM_{2.5}$ concentrations after removing the influence of weather. Noticeable decreases are seen throughout the eastern and north-central United States in the cooler months, while more modest decreases are seen in the warmer months.

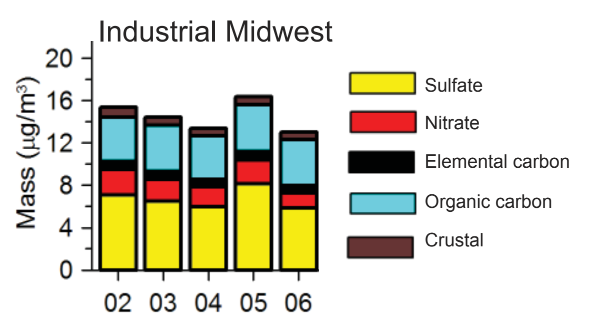

Figure 6. Regional trends in annual $PM_{2.5}$ Concentrations in µg/m^3, 2002-2006.
Note: This figure is based on 12 sites in the States of WI, IL, IN, MI, OH, KY, and PA.
Source: U.S. Environmental Protection Agency (U.S. EPA). 2008b. Latest Findings on National Air Quality: Status and Trends Through 2006. January 2008. EPA-454-R-07-007. http://www.epa.gov/air/airtrends/2007/report/trends_report_full.pdf, last accessed September 18, 2008.

Looking closer at the trends in $PM_{2.5}$ composition in the Midwest and Northeast United States, a decreasing trend can be seen for most components, except for an increased amount in 2005 (Fig. 6). In 2005, the industrial Midwest (including WI, IL, IN, MI, OH, KY, and parts of WV, PA, and NY) had a temporary increase in $PM_{2.5}$ concentrations, mostly due to elevated levels of nitrates and sulfates. The colder-than-normal winter and the hotter-than-normal summer in 2005 are suspected to be the cause of the elevated levels. The former conditions were more conducive to nitrate formation, while the latter conditions were more conducive to sulfate formation and caused higher SO_2 emissions due to higher electrical demand.

There are three areas in the Great Lakes region that are designated nonattainment for the $PM_{2.5}$ standard (Chicago-Gary-Lake Co, IL-IN metropolitan area; Detroit-Ann Arbor, MI metro area; and the Cleveland-Akron-Lorain, OH metro area).

Emissions: In the United States, direct emissions from anthropogenic sources decreased 44% nationally between 1990 and 2002. More recently, it is estimated that annual direct $PM_{2.5}$ emissions decreased by 11% from 2000 to 2006. Changes in how U.S. EPA has compiled national inventories over time may account for some differences. However, this decreasing trend does not account for the formation of secondary particles. Furthermore, this only accounts for anthropogenic direct emissions and not miscellaneous (e.g. wildfires) and natural sources and fugitive dust. These sources may account for as much as 64% of total direct $PM_{2.5}$ emissions.

In Canada, $PM_{2.5}$ emissions (not including open sources such as road dust, construction operations, and forest fires) have decreased nationally by about 30% between 1990 and 2006.

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 vehicle miles/kilometers 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 and that multi-pollutant effects should be addressed.

Management Implications

Major pollution reduction efforts continue in both the United States 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 United States, new, more protective ambient air standards have been promulgated for ozone and particulate matter. MACT standards continue to be promulgated for sources of toxic air pollution. U.S. EPA has also begun looking at the risk remaining after emissions reductions for industrial sources take effect.

At the international level, Canada and the United States 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 United States 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 United States have also undertaken cooperative modeling, monitoring, and data analysis and have developed a work plan to address transboundary PM issues. In 2007, the Canadian Minister of the Environment and U.S. EPA Administrator announced that Canada and the United States will start negotiations on a Particulate Matter Annex to the 1991 U.S.-Canada Air Quality Agreement. A Particulate Matter Annex also would complement the annex negotiated in 2000 addressing ground-level ozone, as well as the original annexes on acid rain and scientific cooperation. $PM_{2.5}$ 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 United States is continuing its deployment of a national air toxics monitoring network.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Coastal Wetland Invertebrate Communities

Indicator #4501

Overall Assessment

Status: **Not Assessed**
Trend: **Not Assessed**
Rationale: **Part of an overall analysis of biological communities of Great Lakes coastal wetlands.**

Note: This is a progress report towards implementation of this indicator, and it 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.

Lake-by-lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To directly measure specific components of invertebrate community composition
- To infer the chemical, physical and biological integrity and range of degradation of Great Lakes coastal wetlands

Ecosystem Objective

Significant wetland areas in the Great Lakes basin that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated (Annex 13 GLWQA). Conducting monitoring and surveillance activities will gather definitive information on the location, severity, aerial or volume extent, and frequency of the Great Lakes coastal wetlands (Annex 11 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

State of the Ecosystem

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 Regional Environmental Monitoring and Assessment Program (REMAP), and others) sampled large numbers of Great Lakes wetlands. In 2002, the Great Lakes Coastal Wetlands Consortium conducted extensive surveys of wetland invertebrates of the four lower Great Lakes. 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 from 1997 to 2001. 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 of Gastropoda, relative abundance of Sphaeriidae, Ephemeroptera plus Trichoptera taxa richness, relative abundance of Crustacea plus Mollusca, relative abundance of 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, Michigan, consistently scored low. 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, Michigan, consistently scored lower than other Saginaw Bay sites.

Burton and Uzarski 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, total genera richness, relative abundance of Isopoda, Shannon Index, Simpson Index, evenness, and relative abundance of Ephemeroptera), the sites studied were placed in the following order of increasing community health: 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.

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, *Phalaris arundinacea*), destruction of inland wet meadow zones by plowing and diking, and addition of herbicides.

Urban development

Urban development degrades wetlands by hardening shoreline, filling wetlands, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increasing nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

Residential shoreline development

Residential development has altered many coastal wetlands via nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the introduction of non-native species.

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 via construction equipment or in introduced sediments.

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 allow many of the most damaging aquatic weeds to out-compete native species. Most of the damaging 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.

Pressures were described by Dennis Albert in the *Coastal Wetland Plant Communities Indicator #4862*.

Management Implementations

Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on a basin-wide scale has not yet occurred. Implementation of a long-term coastal wetland monitoring program is pending; however support for this program is needed by resource managers throughout the basin.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated

State of the Great Lakes 2009

Coastal Wetland Fish Community Health

Indicator #4502

Overall Assessment

Status: **Not Assessed**
Trend: **Not Assessed**
Rationale: **This indicator will be evaluated as part of an overall analysis of biological communities of Great Lakes coastal wetlands and nearshore aquatic systems.**

Note: This is a progress report towards implementation of this indicator, and it 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.

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To assess the fish community composition, and to infer suitability of habitat and water quality for Great Lakes coastal wetland fish communities

Ecosystem Objective

The ecosystem objective of this indicator is to restore and maintain the diversity of the fish community of Great Lakes coastal wetlands while indicating overall ecosystem health. Significant wetland areas in the Great Lakes basin that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated (Annex 13 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

State of the Ecosystem

Development of this indicator is still in progress. However, to evaluate the status of a coastal wetland using fish as indicators, several different fish metrics have been suggested by the Great Lakes Coastal Wetland Consortium:

- mean abundance and richness per (fyke) net-night of resident fish species within dominant inundated vegetation zones, primarily bulrush (*Schoenoplectus*) and cattail (*Typha*)
- across survey stations specific to a vegetation zone
- percent non-native richness;
- mean Shannon Diversity index;
- mean evenness;
- mean abundance and richness of omnivores, insectivores, piscivores, and carnivores (insectivores + piscivores + zooplanktivores).

In order to properly manage Great Lakes coastal wetland fish community health, there must be consistent sampling methods. Sampling should be conducted no earlier than mid-June and no later than August due to migration patterns of the fish communities. Dominant vegetation zones should be identified as different zones support different types of fish. Two main vegetation zones are bulrush and cattail. When sampling fish using fyke netting it is recommended to use a minimum of three replicate fyke nets with 4.8-mm mesh for each dominant vegetation zone. There are two sizes of fyke nets that can be used (0.5-m x 1-m opening and 1-m x 1-m opening). The smaller nets should be placed in water that is 0.25-0.5m deep and the larger fyke nets should be place in water that is greater than 0.50m deep. The lead should be 7.3m long with the wings being 1.8m long. Location of the nets should be 20m apart in each vegetation zone and should be selected randomly. The fyke nets should be placed perpendicular to the vegetation zone therefore fish swimming along the edge of the vegetation zone will be caught.

When sampling using electrofishing techniques, sampling locations must be accessible to boats and conducted within July and August during the peak of the aquatic vegetation, which coincides with the peak of fish diversity. First, sampling transects must be selected. Typically, sampling is completed within in four to five hours when sampling all seven transects. In order to select the transits to be sampled, orthophotoquads can be used to geographically analyze the standing water section of the orthophotoquads. Then the standing water in the orthophotoquads can be divided into seven sections of equal length which will be the seven transects to be sampled. Transects should be clearly identified and recorded using GPS coordinates. When sampling along transects, the dominant vegetation, depth, substrate characteristics, water chemistry, and turbidity should be noted. Small light-weight boats are recommended to conduct electrofishing sampling due to the habitat of coastal wetlands. Cathodes should be made out of three-meter stainless steel cable which will be suspended from the boat rail. Electrical current should be generated using a 5,000 watt generator. There should be 60 to 120 pulses of electricity to achieve maximum results. The current of electricity should be at a level that stuns the fish but has little harmful effects to the fish. Sampling one transect should be completed in within 10 to 15 minutes. When working up the fish, vegetation zones should be noted and the fish should be separated into different coolers based on what type of vegetation they were found in.

Any fish collected using either of these techniques that is greater than 25 mm should be identified to species. The number of the fish caught per fyke net or per minute for electrofishing should be recorded. Also 10 to 20 specimens of each species, life stage and size at age should be chosen randomly to record.

Using the methods stated above, scientists have determined the composition of fish communities is related to plant community type within wetlands (Uzarski *et al*. 2005, Wei *et al*. 2004). Uzarski *et al*. (2005) found no relationship between wetland fish composition and a specific Great Lake, suggesting that fish communities of any single Great Lake were no more impacted than those from any other Great Lake. However, of the 61 wetlands sampled in 2002 from all five Great Lakes, Lake Erie and Lake Ontario tended to have more wetlands containing cattail communities (a plant community type that correlates with nutrient enrichment), and the fish communities found in cattails tended to have lower richness and diversity than fish communities found in other vegetation types. Wetlands found in northern Lake Michigan and Lake 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 Great Lakes.

When the fish communities of reference wetlands are compared across the entire Great Lakes, the most similar sites come from the same ecological province rather than from any single Great Lake or specific wetland type. Data from several Great Lakes Environmental Indicators project studies indicate that the characteristic groups of fish species in reference wetlands from each ecological province tend to have similar water temperature and aquatic productivity preferences.

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 2003. They sampled three lower bay and one middle bay wetland in 2002 and 2003. Their data suggested that these sites were improving in water clarity and plant cover, and that they 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 Green Bay wetlands are improving slowly and the middle bay site seems to be remaining relatively stable in moderately good condition (J. Brazner, personal observation). The most turbid wetlands in the lower bay were characterized by mostly warm-water, turbidity-tolerant species such as gizzard shad (*Dorosoma cepedianum*), white bass (*Morone chrysops*), freshwater drum (*Aplodinotus grunniens*), common shiners (*Luxilus cornutus*), and common carp (*Cyprinus carpio*). Meanwhile 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 (*Morone salmoides*) were also present. There were more banded killifish (*Fundulus diaphanous*) in 1995 and 2003 compared with 1991, and white perch (Morone americana) 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 and Pappas 1992), and they 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 had 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 a few were found in lower Green Bay along the sandy and rocky shoreline west of Little Tail Point.

Uzarski and Burton (unpublished) consistently collected a few round gobies from a fringing wetland near Escanaba, MI, where cobbles were present. In the Muskegon River-Muskegon Lake wetland complex on the eastern shoreline, round gobies are abundant in the heavily rip-rapped harbor entrance to Lake Michigan, and they have just begun to enter the river/wetland complex on the east side of Muskegon Lake (Cooper *et al*. 2007; D. Jude, personal observations). Based on intensive fish sampling prior to 2003 at more than 60 sites spanning all of the Great Lakes, round gobies have not been sampled in large numbers at any wetland or been a dominant member of any wetland fish community (Jude *et al*. 2005). Round gobies were collected at 11 of 80 wetlands sampled by the Great Lakes Environmental Indicators project (Johnson *et al*. unpublished data). Lapointe (2005) assessed fish-habitat associations in the shallow (less than 3 m) Canadian waters of the Detroit River in 2004 and 2005 using boat-mounted electrofishing and boat seining techniques. The round goby avoided complex macrophytes in all seasons at upper, mid-, and downstream segments of the Detroit River. However, in 2006 beach seining surveys at shoreline sites in Canadian waters of Lake St. Clair, the Detroit River, and western Lake Erie, both tubenose and round gobies were collected in areas with aquatic vegetation (L. Corkum, unpublished data). It seems likely that wetlands may be a refuge for native fishes, at least with respect to the influence of round gobies (Jude *et al*. 2005).

There is little information on the habitat preferences of the tubenose goby within the Great Lakes with the exception of studies on the Detroit River (Lapointe 2005), Lake St. Clair and the St. Clair River (Jude and DeBoe 1996, Pronin *et al*. 1997, Leslie *et al*. 2002). Within the Great Lakes, tubenose gobies that were studied at a limited number of sites along the St. Clair River and on the south shore of Lake St. Clair occurred in turbid water associated with rooted submersed vegetation (*Vallisneria americana*, *Myriophyllum spicatum*, *Potamogeton richardsonii* and *Chara* sp.; Leslie *et al*. 2002). Few specimens were found on sandy substrates devoid of vegetation, supporting similar findings by Jude and DeBoe (1996). Leslie *et al*. (2002) collected tubenose gobies in water with no or slow flow on clay or alluvium substrates, where turbidity varies and where rooted vegetation was sparse, patchy or abundant. Lapointe (2005) found that the association between tubenose gobies and aquatic macrophytes differed seasonally in the Detroit River. For example, tubenose gobies were strongly negatively associated with complex macrophytes in the spring and summer, but positively associated with complex macrophytes in the fall (Lapointe 2005). Because tubenose gobies shared habitats with fishes representing most ecoethological guilds, Leslie *et al*. (2002) suggested that the tubenose goby would expand its geographic range within the Great Lakes.

Ruffe (*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 they occurred along with common carp young-of-the-year in many of the wetlands 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 and Ship Canal. Most of these species attain large sizes. Some are planktivorous, but also eat 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 Green 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, but in lower bay wetland sites, 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.

According to Seilheimer and Chow-Fraser (2007), northern coastal wetlands had higher water quality indices than southern lakes coastal wetlands. Lake Superior had a good status while Lake Huron and Georgian Bay were classified with a very good status. Southern coastal wetlands in Lake Ontario, Erie and Michigan were classified as moderately degraded (Seilheimer and Chow-Fraser, 2007).

During this study pumpkinseed occurred in 94 out of 100 wetlands studied, and over 6,000 pumpkinseed individuals were captured. Brown bullhead (*Ameiurus nebulosus*) was the second most abundant fish captured and it was found in 80 wetlands. Another abundant species was the spottail shiner (*Notropis hudsonius*) which was found in 39 coastal wetlands with a little less than 3,800 individual captured. Other abundant species found in the Great Lakes coastal wetlands are the largemouth bass, bluntnose minnow, and the bluegill.

Pressures

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, *Phalaris arundinacea*), destruction of inland wet meadow zones by plowing and diking, and addition of herbicides.

Urban development

Urban development degrades wetlands by hardening shoreline, filling wetlands, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increasing nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

Residential shoreline development

Residential development has altered many coastal wetlands via nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the establishment of non-native species. Shoreline hardening can completely eliminate wetland vegetation, which results in degradation of fish habitat. It appears that when a wetland becomes affected by human development, the fish community changes to that typical of a warmer, richer, more southerly wetland. This finding may help researchers anticipate the likely effects of regional climate change on the fish communities of Great Lakes coastal wetlands.

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 via 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 allow many of the most damaging aquatic weeds to outcompete native species. Most of the most damaging 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.

Management Implications

Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on a basin-wide scale has not yet occurred. Implementation of a long-term coastal wetland monitoring program is pending; however support for this program is needed by resource managers throughout the basin.

Assessing Data Quality

Insert "x" under the statement that best corresponds with each data characteristic.

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

Acknowledgments

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Last Updated
State of the Great Lakes 2009

Coastal Wetland Amphibian Communities
Indicator #4504

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**
Rationale: **Species across the Great Lakes basin exhibited both positive and negative population trend tendencies. Four species exhibited significantly negative population trends while only one species exhibited a significantly positive population trend.**

Lake-by-Lake Assessment

Lake Superior
Status: Not Assessed
Trend: Undetermined

Lake Michigan
Status: Mixed
Trend: Deteriorating
Rationale: Most species in this lake basin exhibited negative population trend tendencies, three of which were significant. Though two species exhibited positive trends, neither of these was significant.

Lake Huron
Status: Mixed
Trend: Deteriorating
Rationale: Species in this lake basin exhibited both positive and negative population trend tendencies. However, three out of eight species exhibited significantly negative population trends. There were no significantly positive population trends.

Lake Erie
Status: Mixed
Trend: Unchanging
Rationale: Species in this lake basin exhibited both positive and negative population trend tendencies. Of the two species with significant population trends, one was positive and one was negative.

Lake Ontario
Status: Mixed
Trend: Deteriorating
Rationale: Species in this lake basin exhibited both positive and negative population trend tendencies. Three species exhibited significant negative population trends, and no significant positive trends were observed.

Purpose
- To directly measure species composition and relative occurrence of frogs and toads
- 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 biotic communities

Ecosystem Objective
The overall 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. Significant wetland areas in the Great Lakes basin that are threatened by

urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated (Annex 13 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

State of the Ecosystem

Background

Numerous amphibian species occur in the Great Lakes basin and many of these are associated with wetlands during part of their life cycle. Because frogs and toads are relatively sedentary and have semi-permeable skin, they are likely to be more sensitive to, and indicative of, local sources of wetland contamination and degradation than are most other vertebrates. Assessing species composition and relative abundance of calling frogs and toads in Great Lakes wetlands can therefore help to infer wetland habitat quality.

Status of Amphibians

Since 1995, Marsh Monitoring Program (MMP) volunteers have collected amphibian data at 691 discrete routes across the Great Lakes basin. An annual summary of monitored amphibian routes is provided in Table 1.

Year	Number of Routes
1995	119
1996	181
1997	210
1998	171
1999	166
2000	159
2001	169
2002	197
2003	159
2004	152
2005	181
2006	240
2007	254

Table 1. Number of routes surveyed for amphibians within the Great Lakes basin, from 1995 to 2007.
Source: Marsh Monitoring Program.

Thirteen amphibian species were recorded during the 1995 to 2007 period (Table 2). Spring peeper (*Pseudacris crucifer*) was the most frequently detected species and was commonly recorded in full chorus (Call Level Code 3) when it was encountered. Green frog (*Rana clamitans*) was detected in more than half of the survey stations and was most often recorded at Call Level Code 1 (calling individuals could be discretely counted). Gray treefrog, (*Hyla* sp.), American toad (*Bufo americanus*) and northern leopard frog (*Rana pipiens*) were also common, being recorded in approximately one-third or more of all survey stations. Gray treefrog was recorded with the second highest average calling code (1.8), indicating that MMP observers usually heard several individuals calling simultaneously at each survey station. Chorus frog, bullfrog (*Rana catesbeiana*) and wood frog (*Rana sylvatica*) were detected in approximately one-quarter of survey stations, while the remaining five species were detected in less than 3% of survey stations.

Species	Percent Station-Years Present[1]	Average Calling Code
Spring Peeper	68.8	2.5
Green Frog	55.6	1.3
Gray Treefrog	38.9	1.8
American Toad	37.2	1.5
Northern Leopard Frog	31.0	1.3
Chorus Frog	26.5	1.7
Bullfrog	25.8	1.3
Wood Frog	18.0	1.6
Pickerel Frog	2.4	1.1
Fowler's Toad	2.2	1.4
Cope's Gray Treefrog	1.2	1.4
Mink Frog	1.2	1.2
Blanchard's Cricket Frog	0.6	1.7

[1]MMP survey stations monitored for multiple years considered as individual samples

Table 2. Frequency of occurrence (Percent Station-Years Present) and average Call Level Code for amphibian species detected at MMP survey stations within the Great Lakes basin, from 1995 through 2007.
Average calling codes are based on the three level call code standard for all MMP amphibian surveys; Code 1 = little overlap among calls, numbers of individuals can be determined, Code 2 = some overlap, numbers can be estimated, Code 3 = much overlap of calls, too numerous to be estimated.
Source: Marsh Monitoring Program.

Trends in amphibian occurrence were assessed for eight species commonly detected on MMP routes (Fig. 1). For each species, the annual proportion of stations where that species was present within a route was calculated to derive annual indices of occurrence. The overall temporal trend in occurrence for each species was assessed by combining route-level trends in station occurrence. Statistically significant declining trends were detected for American toad, chorus frog, green frog and northern leopard frog. No commonly detected species exhibited significant positive trends. While mink frog (*Rana septentrionalis*) exhibited a significantly increasing trend, its low occurrence frequency across MMP surveys between 1995 and 2007 makes this result less certain.

Anecdotal and research evidence suggests that wide variations in occurrence of many amphibian species at a given site is a natural and ongoing phenomenon. Additional years of data will help distinguish whether the patterns observed (i.e., decline in American toad, chorus frog, green frog and northern leopard frog population indices) indicate significant long-term trends or simply natural variation in population sizes inhabiting marsh habitats. It has been observed, for example, that bullfrog, green frog, and spring peeper populations reflect changes in lake levels

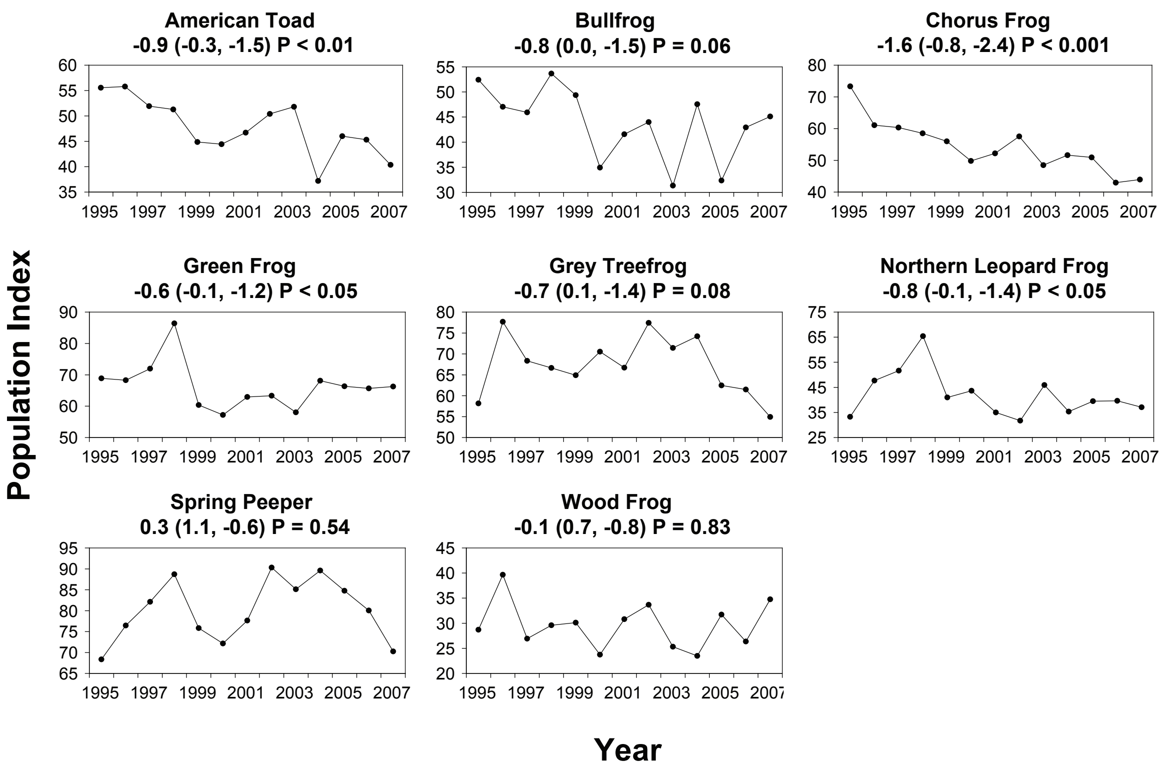

Figure 1. Trends (percent annual change) in station occurrence (population index) of eight amphibian species commonly detected at Marsh Monitoring Program routes, from 1995 to 2007.
Values in parentheses are upper and lower 95% confidence limits, respectively, for trend values given.
Source: Marsh Monitoring Program.

to some degree, which can account for some year-to-year variation (Timmermans 2001). Chorus frog, on the other hand, has exhibited a relatively consistent negative population index trend since 1995, suggesting that its decline may be influenced by factors beyond year-to-year variation. However, it would appear that, in general, Great Lakes wetlands are impaired in their ability to successfully sustain amphibian populations, an assessment that can be made with more confidence as further data are gathered. MMP amphibian data are being evaluated to determine how information from amphibian community composition can be used to gain a better understanding of Great Lakes coastal wetland condition in response to various human induced stressors.

An amphibian community-based coastal wetland Index of Biotic Integrity (Timmermans *et al*, 2008), was calculated for Lake Ontario and Lake Erie sites that had been monitored by MMP participants between 1995 and 2007. Within the Lake Erie basin, the Mentor Marsh, Long Point 7, and Turkey Point sites ranked highest, with mean IBI scores above 88.0 for each. However, the Long Point 7 and Turkey Point site means were only based on one and two years of data, respectively. The Long Pond wetland of Presque Isle State Park, which was monitored for 11 years, ranked fourth with a mean IBI of 85.1. Within the Lake Ontario basin, three sites (Presqu'ile Bay 4, South Bay 1, and Button Bay 2) had mean IBIs above 99.0 for each. However, each of these sites was only monitored for one year. Big Island Marsh, which had been monitored for 13 years, was ranked fourth with a mean IBI of 96.0. In total, six Lake Ontario coastal sites achieved an IBI score of above 90.0.

While this IBI might prove informative to rank relative condition of wetland habitats within lake basins, the results should be interpreted with caution. For example, while the IBI responded significantly to disturbance across all years (1995-2007), it responded more strongly to years of relatively high Great Lakes water level (1995-1998) than to years of relatively low Great Lakes water level (1999-2007). Further, variation in the number of survey years among sites, and the non-random site distribution should be considered. Refer to Crewe and Timmermans (2005) for additional information.

Pressures
Habitat loss and deterioration remain the predominant threat to Great Lakes amphibian populations. Many coastal and inland Great Lakes wetlands are located along watersheds that experience very intensive industrial, agricultural and residential development. Therefore, these wetlands are under continued stress as increased pollution from anthropogenic runoff is washed down watersheds into these sensitive habitats. Combined with other impacts such as water level stabilization, sedimentation, contaminant and nutrient inputs, climate change and invasion of non-native species, Great Lakes wetlands will likely continue to be degraded and as such, should continue to be monitored.

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 high-quality wetland habitat as well as associated upland areas adjacent to coastal wetlands. There is also a need to address other impacts that are detrimental to wetland health such as inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made in this area, more work remains for many wetland areas that have yet to receive restoration efforts.

Comments from the author(s)
Effective monitoring of Great Lakes amphibians requires accumulation of many years of data, using a standardized protocol, over a large geographic expanse. As such, efforts should be pursued among the various call-count based anuran monitoring programs operating within the Great Lakes basin to enhance coordination, communication and cooperation, and to standardize protocols where possible, in order to improve anuran population status and trend reporting. A reporting frequency for SOLEC of five years would be appropriate because amphibian populations naturally fluctuate through time, and a five-year timeframe would be sufficient to indicate noteworthy changes in population indices. More rigorous studies will relate trends in species occurrence or relative abundance to environmental factors. Reporting will be improved with establishment of a network of survey routes that accurately represent the full spectrum of marsh habitat in the Great Lakes basin.

Most MMP amphibian survey routes have been georeferenced to the survey station level. Volunteer recruitment has also improved significantly since the last status reporting period, and with the recent development of an MMP regional coordinator network throughout the Great Lakes basin, improved local and regional delivery of the program is anticipated. Two additional important tasks are in progress: 1) improvement of the program's capacity to monitor and report on status of wetland-specific Beneficial Use Impairments among Great Lakes Areas of Concern, and; 2) development and improvement of the program's capacity to train volunteer participants to identify and survey amphibians following standard MMP protocols. Also, further work is required to determine the relationship between calling codes used to record amphibian occurrence and survey count estimates.

Geographically extensive and long-term monitoring of calling amphibians is possible through the enthusiasm, skill and coordination of volunteer participants trained in the application of standardized monitoring protocols. Information about abundance, distribution and diversity of amphibians provides data for calculating trends in population indices as well as investigating habitat associations, which can contribute to effective long-term conservation strategies.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Contaminants in Snapping Turtle Eggs

Indicator #4506

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Contaminants at Great Lakes Areas of Concern (AOCs) exceeded concentrations at reference sites. Dioxin equivalents and Dichlorodiphenyldichloroethylene (DDE) concentrations in eggs exceeded the Canadian Environmental Quality Guidelines, and sum polychlorinated biphenyls (PCBs) from some sites exceeded partial restriction guidelines for consumption.**

Lake-by-Lake Assessment

Lake Superior
Status: Not Assessed
Trend: Undetermined
Rationale: Insufficient data

Lake Michigan
Status: Not Assessed
Trend: Undetermined
Rationale: Insufficient data

Lake Huron
Status: Not Assessed
Trend: Undetermined
Rationale: Insufficient data

Lake Erie
Status: Mixed
Trend: Undetermined
Rationale: Contaminants at AOCs exceeded concentrations at reference sites. Dioxin equivalents and DDE concentrations in eggs exceeded the Canadian Environmental Quality Guidelines, and sum PCBs from some sites exceeded partial restriction guidelines for consumption.

Lake Ontario
Status: Mixed
Trend: Undetermined
Rationale: Contaminants at AOCs exceeded concentrations at reference sites. Dioxin equivalents and DDE concentrations in eggs exceeded the Canadian Environmental Quality Guidelines, and sum PCBs from some sites exceeded partial restriction guidelines for consumption.

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
- 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 (*Chelydra serpentina serpentina*) 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 (United States and Canada 1987).

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, Environment Canada's 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, from 2001 to 2005, CWS examined the health of snapping turtles relative to contaminant exposure in Canadian Areas of Concern (AOCs) of the lower Great Lakes basin. American researchers have also recently used snapping turtles as indicators of contaminant exposure (Dabrowska *et al*. 2006).

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 PCBs and organochlorines among the study sites (Bishop *et al*. 1996; 1998). Eggs from Akwesasne (St. Lawrence River) contained the greatest level of PCBs tested (Bishop *et al*. 1998). From 1984 to 1990/1991, levels of polychlorinated biphenyls (PCBs) and dichlorodiphenyldichloroethylene (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 to 1991 were highest at all four Lake Ontario sites compared to other sites studied (Bishop *et al*. 1998).

Lake Erie and connecting channels

From 2001 to 2003, CWS collected snapping turtle eggs at or near three Canadian Lake Erie or connecting channels AOCs: Detroit River, St. Clair River, and Wheatley Harbour, as well as two reference sites. Mean sum PCBs ranged from 0.02 µg/g at Algonquin Provincial Park (a reference site) to 0.93 µg/g at Detroit River. Sum PCB levels were highest at Detroit River (Turkey Creek), followed by Wheatley Harbour, then St. Clair National Wildlife Area (near the St. Clair River AOC) and lastly, Algonquin Provincial Park (Fig. 1). Dioxin equivalents of sum PCBs in eggs from the Detroit River, Wheatley Harbour, and St. Clair River AOCs, and DDE levels in eggs from the Wheatley Harbour and the Detroit River AOCs exceeded the Canadian Environmental Quality Guidelines. Sum PCBs in eggs from the Detroit River and Wheatley Harbour AOCs exceeded partial restriction guidelines for consumption (de Solla and Fernie 2004).

An American study in 1997 funded by the Great Lakes Protection Fund found that sum PCBs in snapping turtle tissues and eggs appeared to be higher in the American AOCs in Ohio, where concentrations ranged from 0.18 to 3.68 µg/g. Concentrations were highest in turtles from the Ottawa River AOC, followed by the Maumee River AOC, Ashtabula River AOC, and the Black River within the Maumee River AOC (Dabrowska *et al*. 2006). The reference sites used near the American AOCs may have higher contaminant exposure than the Canadian reference sites.

Lake Ontario and connecting channels

From 2002 to 2003, CWS collected snapping turtle eggs at or near seven Lake Ontario and connecting channel AOCs: Hamilton Harbour (2 sites), Niagara River (ON), St. Lawrence River (ON), and Toronto, as well as two reference sites. Mean sum PCB levels ranged from 0.02 µg/g at Algonquin Park (the 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 Niagara River (Lyons Creek) (Fig. 1). There is evidence that PCB levels in snapping turtle eggs have been declining at the inland reference site of Algonquin Park (from 1981 to 2003) and at the heavily contaminated Hamilton Harbour AOC (from 1984 to 2003). Long term trends at the St. Lawrence River AOC are difficult to determine due to the high degree of variability of contaminant sources in the area. PCB levels have been reported as high as 738 µg/g at Turtle Creek, Akwesasne (de Solla *et al*. 2001).

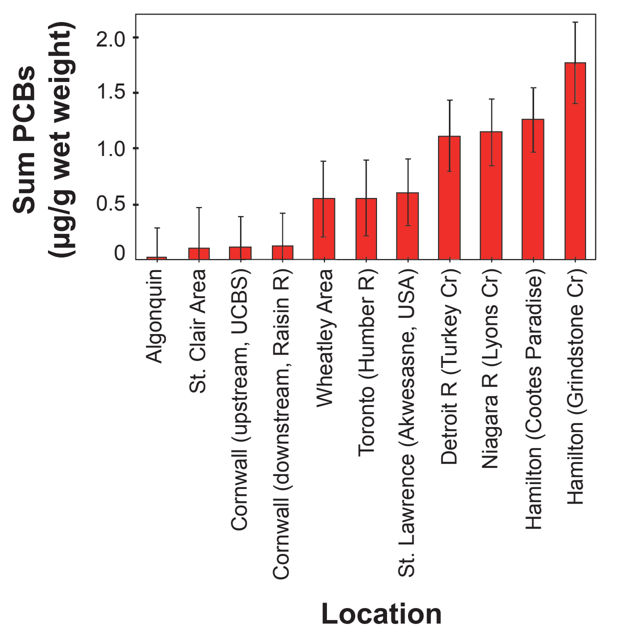

Figure 1. Sum PCB concentrations in snapping turtle eggs from various Canadian locations throughout the lower Great Lakes basin, 2001 through 2003.
Means ± standard errors are presented.
Source: Canadian Wildlife Service.

Flame retardants (PBDEs) are one of the chemicals of emerging concern because they are bioaccumulative and may potentially affect wildlife and human health. Sum PBDE concentrations varied, but they were an order of magnitude lower than sum PCBs in snapping turtle eggs collected from the seven AOCs (2001 to 2003). Sum PBDE levels were lowest at Algonquin Park (6.1 ng/g), where airborne deposition is likely the main contaminant source, and greatest at the Hamilton Harbour (Cootes Paradise: 67.6 ng/g) and Toronto (Humber River: 107.0 ng/g) AOCs. This is 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 and dioxins), as well as contaminants whose concentrations are expected to increase in Great Lakes wetlands (e.g., PBDEs). Non-bioaccumulative compounds in which there are chronic exposures (e.g., polycyclic aromatic hydrocarbons (PAHs)) also pose a potential threat. Snapping turtle populations face additional pressures from harvesting of adult turtles, road-side killings during the nesting season in June, and habitat destruction.

Management Implications

The contaminants measured are persistent and bioaccumulative. Diet is the primary source of exposure to contaminants for snapping turtles, and thus levels of contaminants in turtle tissue or eggs reflect contamination that is available throughout the aquatic food web. Although commercial collection of snapping turtles has ceased, collection for private consumption persists. Therefore, consumption restrictions are required at selected AOCs. Currently, only eggs are routinely sampled for contaminants, but body burdens of females could be estimated using egg burdens, and thus used for determining if consumption guidelines are needed. At some AOCs (i.e., Niagara River (Lyons Creek), and Hamilton Harbour), there are localized sediment sources of contaminants that may be rehabilitated through dredging or capping. Mitigation of contaminant sources should eventually reduce contaminant burdens in snapping turtles.

Comments from the author(s)

Contaminant status of snapping turtles should be monitored on a regular basis across the Great Lakes basin where appropriate. Once the usefulness of the indicator is confirmed, a complementary U.S. program is required to interpret basin-wide trends. This species offers an excellent opportunity to monitor contaminant concentrations in coastal wetland populations. Newly emerging contaminants also need to be examined in a long-term monitoring program. As with all long-term monitoring programs, and for any indicator species used to monitor persistent bioaccumulative contaminants, standardization of contaminant data is necessary for examining temporal and spatial trends or combining data from different sources.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization						
2. Data are traceable to original sources						
3. The source of the data is a known, reliable and respected generator of data						
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin						
5. Data obtained from sources within the U.S. are comparable to those from Canada						
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report						
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2007

Coastal Wetland Bird Communities
Indicator #4507

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**
Rationale: **Species across the Great Lakes basin exhibited both positive and negative population trend tendencies. Significantly negative population trends occurred for 18 species, while only six species exhibited significantly positive population trends.**

Lake-by-Lake Assessment

Lake Superior
Status: Not Assessed
Trend: Undetermined

Lake Michigan
Status: Mixed
Trend: Deteriorating
Rationale: Species in this lake basin exhibited both positive and negative population trend tendencies. Of the seven significant population trends observed, three were positive, while four were negative.

Lake Huron
Status: Poor
Trend: Deteriorating
Rationale: Most species in this lake basin exhibited negative population trend tendencies. Twelve significantly negative population trends occurred, while there were no significantly positive population trends.

Lake Erie
Status: Mixed
Trend: Deteriorating
Rationale: Species in this lake basin exhibited both positive and negative population trend tendencies. Significantly negative population trends occurred for twelve species, while only three species exhibited significantly positive population trends.

Lake Ontario
Status: Mixed
Trend: Deteriorating
Rationale: Species in this lake basin exhibited both positive and negative population trend tendencies. Significantly negative population trends occurred for thirteen species, while only four species exhibited significantly positive population trends.

Purpose
- To assess wetland bird species composition and relative abundance
- 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 biotic communities

Ecosystem Objective

The ecosystem objective is to restore and maintain diverse and self-sustaining populations of Great Lakes coastal wetland bird communities. Breeding populations of bird species across their historical range should be sufficient to maintain populations of each species and overall species diversity. This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

State of the Ecosystem

Background

Assessments of wetland-dependent bird diversity and abundance in the Great Lakes are used to evaluate health and function of coastal and inland wetlands. Breeding birds are valuable components of Great Lakes wetlands and rely on the physical, chemical and biological condition of their habitats, particularly during breeding. Presence and abundance of breeding individuals therefore provide a valuable source of information about wetland status and population trends. Because several wetland-dependent birds are listed as species-at-risk due to the loss and degradation of their habitats, the combination of long-term monitoring data and analysis of habitat characteristics can help to assess how well Great Lakes coastal wetlands are able to provide habitat for these sensitive species as well as other birds and wetland-dependent wildlife.

Status of Wetland-Dependent Birds

Since 1995, Marsh Monitoring Program (MMP) volunteers have collected bird data at 610 discrete routes across the Great Lakes basin. An annual summary of bird routes monitored is provided in Table 1.

Year	Number of Routes
1995	150
1996	181
1997	181
1998	150
1999	156
2000	152
2001	147
2002	172
2003	132
2004	121
2005	185
2006	227
2007	224

Table 1. Number of routes surveyed for marsh birds within the Great Lakes basin, from 1995 to 2007.
Source: Marsh Monitoring Program.

From 1995 through 2007, MMP volunteers recorded 56 bird species that use marshes (wetlands dominated by non-woody emergent plants) for feeding, nesting or both throughout the Great Lakes basin. In 2007, red-winged blackbird (*Agelais phoeniceus*) was the most commonly recorded non-aerial foraging bird species observed by MMP participants, followed by swamp sparrow (*Melospiza georgiana*), yellow warbler (*Dendroica petechia*), and marsh wren (*Telmatodytes palustris*). Among birds that nest exclusively in marsh habitats, the most commonly recorded species was marsh wren, followed by undifferentiated common moorhen (*Gallinula chloropus*)/ American coot (*Fulica americana*) (calls of these two species are difficult to distinguish from one another), Virginia rail (*Railus limicola*), black tern (*Chlidonias n. nigra*), common moorhen, pied-billed grebe (*Podilymbus podiceps*), American bittern (*Botaurus lentiginosus*), American coot, sora (*Porzana carolina*) and least bittern (*Ixobrychus exilis*). Among bird species that typically forage in the air above marshes, tree swallow (*Tachycineta bicolor*) and bank swallow (*Riparia riparia*) were the two most commonly recorded bird species.

Another study, focusing on wetlands in Lake Michigan and Lake Superior, found a similar pattern in relative bird abundance, with red-winged blackbird being the most commonly observed non-aerial foraging bird, followed by swamp sparrow, common yellowthroat (*Geothlypis trichas*), song sparrow (*Melospiza melodia*), and yellow warbler (Hanowski *et al*. 2007). Obligate marsh-breeders, such as sora and Virginia rail, showed moderate-to-low abundance (mean abundance of 0.25 and 0.19 individuals per site, respectively) when compared with generalist species like red-winged blackbird (5.38), song sparrow (1.25) and common grackle (*Quiscalus quiscula*) (1.89). Tree swallow and cliff swallow (*Hirundo pyrrhonota*) were the two most commonly observed aerial foragers.

With thirteen years of data collected across the Great Lakes basin, the MMP is becoming an established and recognized long-term marsh bird population monitoring program. Bird species occurrence, abundance, activity and delectability 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 2007 (Fig. 1). Species with significant basin-wide declines were American coot (not shown), barn swallow (*Hirundo rustica*) (not shown), black tern, blue-winged teal (*Anas discors*) (not shown), Canada goose (*Branta canadensis*) (not shown), common grackle (not shown), common moorhen (not shown), common nighthawk (*Chordeiles minor*) (not shown), Forster's tern (*Sterna forsteri*) (not shown), least bittern, undifferentiated common moorhen/American coot, mute swan (*Cygnus olor*) (not shown), northern harrier (*Circus cyaneus*) (not shown), pied-billed grebe, red-winged blackbird, sora, tree swallow and Virginia rail (Fig. 1). Statistically significant basin-wide population increases were observed for common yellowthroat, great blue heron (*Ardea herodias*) (not shown), northern rough-winged swallow

(*Stelgidopteryx serripennis*) (not shown), trumpeter swan (*Cygnus buccinators*) (not shown), wood duck (*Aix sponsa*) (not shown) and yellow warbler (not shown). American bittern, mallard (*Anas platyrhynchos*) and marsh wren populations did not show a significant trend in abundance indices from 1995 through 2007 (Fig. 1). Declines in population indices of species that use wetlands almost exclusively for breeding such as least bittern, black tern, common moorhen, American coot, sora, pied-billed grebe and Virginia rail, combined with an increase in some wetland edge and generalist species (e.g., common yellowthroat, great blue heron and yellow warbler) suggest changes in wetland habitat conditions may be occurring. Difference in habitats, regional population densities, timing of survey visits, annual weather variability and other factors likely interplay with water levels to explain variation in wetland-dependent bird populations. American bittern, for example, showed a significant declining population index from 1995 to 2004 (Crewe *et al*. 2006) but recently its population index has rebounded. As such, further years of data will hopefully help explain natural population variation from significant population trends.

A bird community-based coastal wetland Index of Biotic Integrity (Grabas *et al*. 2008) was calculated for Lake Ontario and Lake Erie sites that had been monitored by MMP participants between 1995 and 2007. Within the Lake Erie basin, the Black Creek wetland and the Chenal Ecarte (Snye River) marshes ranked highest, with mean IBI scores of 94.3 and 93.1, respectively. While the Black Creek wetland was only monitored for one year, the Chenal Ecarte marshes were monitored for nine years. Within the Lake Ontario basin, the French Creek marsh ranked highest (mean IBI score of 89.1), followed by Presqu'ille Bay Marsh 4 and Hay Bay Marsh 3 (mean IBI scores of 88.3 and 87.4, respectively). Several of the highest ranking Lake Ontario sites were only monitored for three or fewer years, predominantly since 2005.

While this IBI might prove informative to rank relative condition of wetland habitats within lake basins, the results should be interpreted with caution. For example, while the IBI responded significantly to disturbance variables across all years (1995-2007), it responded more strongly to years of relatively high Great Lakes water level (1995-1998) than to years of relatively low Great Lakes water level (1999-2007). Further, variation in the number of survey years among sites, and the non-random site distribution should be considered when interpreting results. Finally, studies have suggested that the two survey visits employed by the MMP may result in lower the detection probabilities for marsh obligate nesting species relative to three annual visits (Tozer 2002; Gibbs and Melvin 1993). Refer to Crewe and Timmermans (2005) for additional information.

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.

Management Implications

Wherever possible, efforts should be made to maintain high quality wetland habitat and adjacent upland areas. There is also a need to address other impacts that are detrimental to wetland health such as water level stabilization, invasive species, and inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made, considerably more conservation and restoration work is needed to ensure maintenance of healthy and functional wetland habitats throughout the Great Lakes basin.

Comments from the author(s)

MMP wetland monitoring activities will continue across the Great Lakes basin. Continued monitoring is projected to provide good resolution for most of the wetland-dependent birds recorded by MMP volunteers. Recruitment and retention of program participants will therefore continue to be a high priority. Priority should also be placed on establishing regional goals and acceptable thresholds for species-specific abundance indices and species community compositions. Assessments to determine relationships among survey indices, bird population parameters and critical environmental parameters are also needed.

MMP staff have engaged in efforts with other marsh bird experts to develop and implement continentally standardized marsh bird monitoring protocols. Recently, the MMP marsh bird monitoring protocol was revised to align with this accepted standardized protocol. These revisions will facilitate improved data sharing and compatibility among most major marsh bird monitoring programs, and will thus improve our knowledge of marsh bird population status and trends across various spatial scales. MMP staff will continue to seek opportunities to work cooperatively with existing monitoring programs in various regions of the Great Lakes basin.

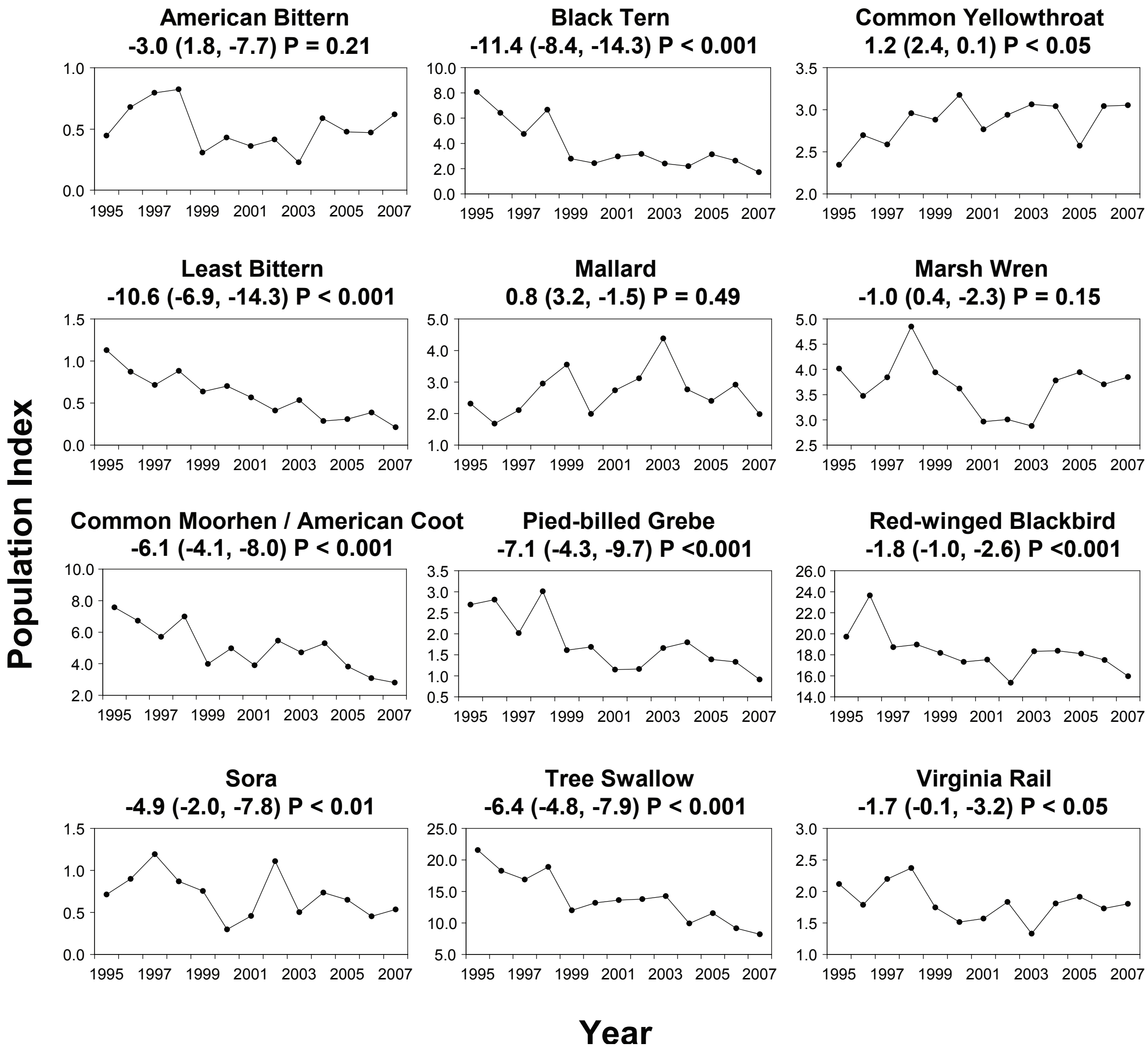

Figure 1. Trends (percent annual change) in relative abundance (population index) of marsh nesting and aerial foraging bird species detected at Marsh Monitoring Program routes, from 1995 to 2007.
Values in parentheses are upper and lower 95% confidence limits, respectively, for trend values given.
Source: Marsh Monitoring Program.

Previous studies have ascertained marsh bird habitat associations using MMP bird and habitat data. As more data are accumulated, these studies should be periodically updated in order to provide a better understanding of the relationships between wetland bird species and habitat. Most MMP bird survey routes have been georeferenced to the level of individual survey stations. Volunteer recruitment has also improved significantly since the last status reporting period, and with the recent development of an MMP regional coordinator network throughout the Great Lakes basin, improved local and regional delivery of the program is anticipated. Future work will focus to enhance the utility of the SOLEC wetland bird indicator by applying the bird community-based IBI to evaluate coastal wetland health. Two additional important tasks are in progress: 1) improve the program's capacity to monitor and report on status of wetland specific Beneficial Use Impairments (BUI) among Great Lakes Areas of Concern (AOCs), and; 2) develop and improve the program's capacity to train volunteer participants to identify and survey marsh birds following standard MMP protocols.

Although more frequent updates are possible, reporting trends in marsh bird population indices every five or six years is most appropriate for this indicator. A variety of efforts are underway to enhance reporting breadth and efficiency.

Geographically extensive and long-term monitoring of wetland-dependent birds is possible through the enthusiasm, skill and coordination of volunteer participants trained in the application of standardized monitoring protocols. Information about abundance, distribution and diversity of marsh birds provides data for calculating trends in population indices as well as investigating habitat associations which can contribute to effective, long-term conservation strategies.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Landscape Extent and Composition

Indicator #4510

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**
Rationale: **To monitor losses of coastal wetland area due to human actions and gains to coastal wetlands due to restoration activities.**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undermined trend, indicating that assessments were not made on an individual lake basis.

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 aerial 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, United States and Canada 1987).

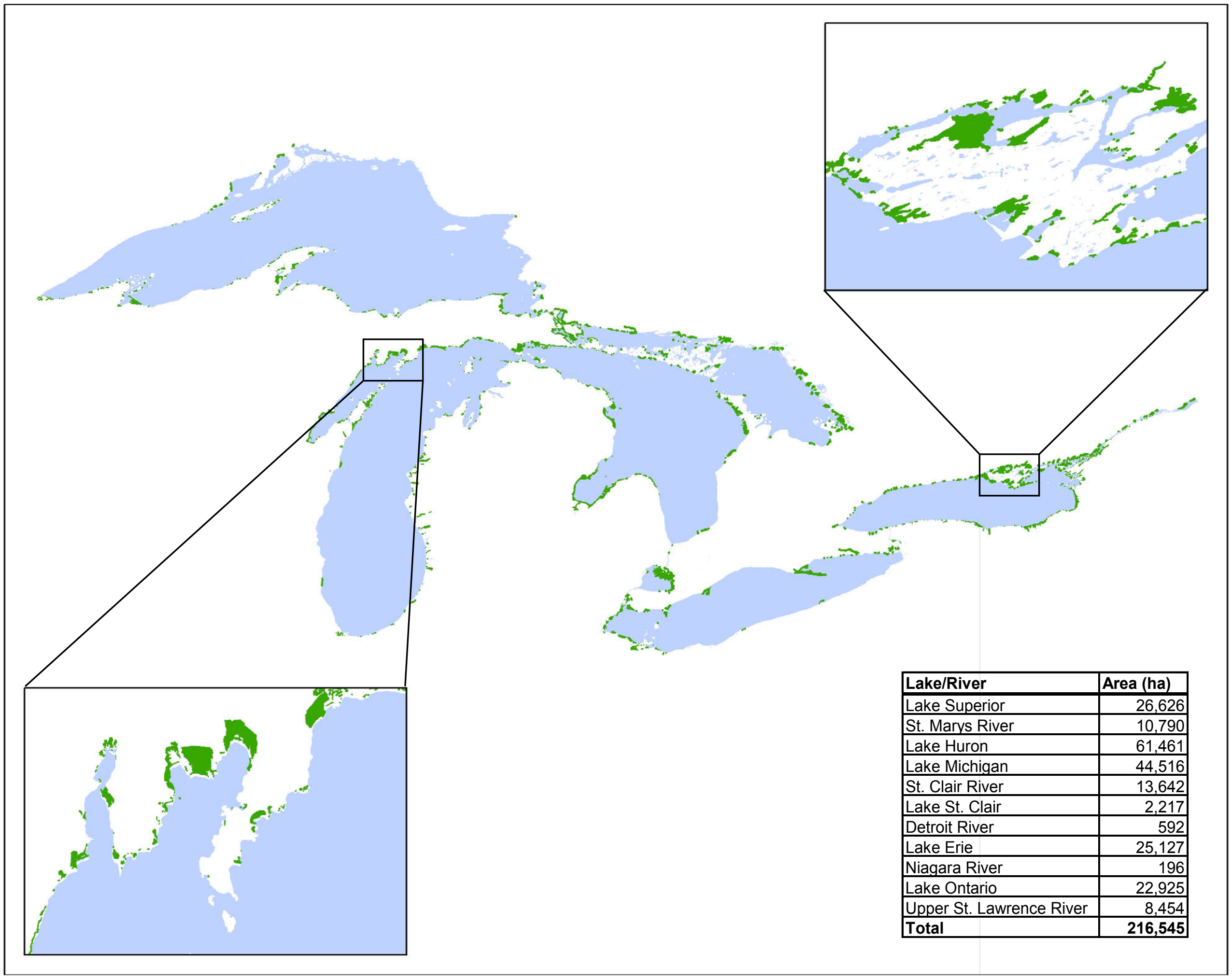
State of the Ecosystem

The status of this indicator has not been updated since the State of the Great Lakes 2005 report. Future updates to the status of this indicator will require the repeated collection and analysis of remotely-sensed information. Currently, technologies and methods are being assessed for an ability to estimate wetland extent. Next steps, including determination of funding and resource needs, as well as pilot investigations, must occur before an indicator status update can be made. The timeline for this is not yet determined. However, once a methodology is established, it will be applicable for long-term monitoring for this indicator, which is imperative for an improved understanding of wetland functional responses and adaptive management. The 2005 assessment of this indicator follows.

Despite the fact that several wetland restoration and protection efforts have improved specific areas, wetlands continue to be lost and degraded. The ability to track and determine the extent and rate of this loss in a standardized way is not yet feasible.

In an effort to estimate the extent of coastal wetlands in the basin, the Great Lakes Coastal Wetland Consortium (GLCWC) coordinated completion of a binational coastal wetland database. The project involved building from existing Canadian and U.S. coastal wetland databases (Environment Canada and Ontario Ministry of Natural Resources 2003; Herdendorf *et al*. 1981a-f) and incorporating additional auxiliary federal, provincial and state data to create a more complete, digital Geographic Information System (GIS) vector database. All coastal wetlands in the database were classified using a Great Lakes hydrogeomorphic coastal wetland classification system (Albert *et al*. 2005). The project was completed in 2004. The GIS database provides the first spatially explicit seamless binational summary of coastal wetland distribution in the Great Lakes system. Coastal wetlands totaling 216,743 ha (535,582 acres) have been identified within the Great Lakes and connecting rivers up to Cornwall, ON (Fig. 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 (150,000 acres) of the identified coastal wetland area in Lake Superior, Lake Huron and Lake Michigan (Fig. 2). Lake Erie supports 22,000 ha (54,500 acres) of coastal wetland, with protected embayment wetlands accounting for over one third of the total area (Fig. 2). In Lake Ontario, barrier protected and drowned rivermouth coastal wetlands account for 19,000 ha (47,000 acres), approximately three quarters of the total coastal wetland area.



Lake/River	Area (ha)
Lake Superior	26,626
St. Marys River	10,790
Lake Huron	61,461
Lake Michigan	44,516
St. Clair River	13,642
Lake St. Clair	2,217
Detroit River	592
Lake Erie	25,127
Niagara River	196
Lake Ontario	22,925
Upper St. Lawrence River	8,454
Total	**216,545**

Figure 1. Great Lakes coastal wetland distribution and total area by lake and river.
Source: Great Lakes Coastal Wetlands Consortium.

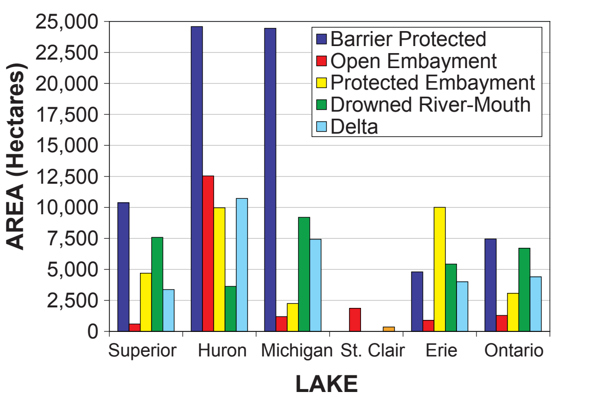


Figure 2. Coastal wetland area by geomorphic type within lakes of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium.

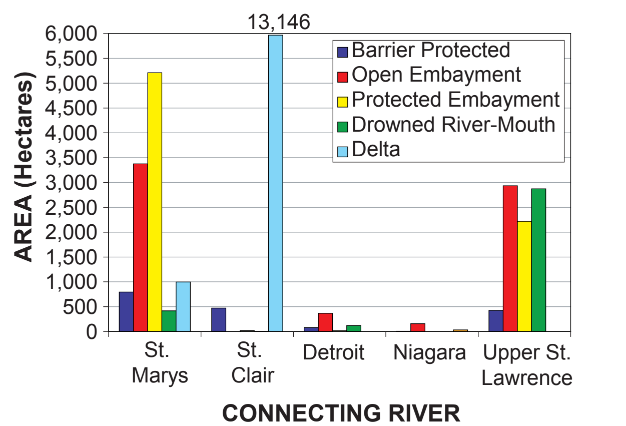


Figure 3. Coastal wetland area by geomorphic type within connecting rivers of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium.

Connecting rivers within the Great Lakes system also support a diverse and significant quantity of wetlands (Fig. 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 (32,000 acres). 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 contributed and continue to contribute to the loss and degradation of coastal wetland area. These include: filling, dredging and draining for conversion to other uses such as urban, agricultural, marina, and cottage development; shoreline modification; water level regulation; sediment and nutrient loading from watersheds; adjacent land use; invasive species, particularly non-native species; and climate variability and change. The natural dynamics of wetlands must be considered in addressing coastal wetland stressors. Global climate variability and change have the potential to amplify the dynamics by reducing water levels in the system in addition to changing seasonal storm intensity and frequency, water level fluctuations and temperature.

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, *Phalaris arundinacea*), destruction of inland wet meadow zones 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 wetlands, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increasing nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

Residential shoreline development

Residential development has altered many coastal wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the 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 via 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 allow many of the most damaging aquatic weeds to out-compete native species. Most of the most damaging 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 most damaging non-native species has been Asian carp; these species' mating and feeding result in loss of submergent vegetation in shallow marsh waters.

Pressures were described by Dennis Albert in the *Coastal Wetland Plant Communities Indicator #4862*.

Management Implications

Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on a basin-wide scale has net yet occurred. Implementations of a long-term coastal wetland monitoring program is pending, however support for this program is needed by resource managers throughout the basin.

Many of the pressures result from direct human actions, and thus, with proper consideration of the impacts, can be reduced. Several organizations have designed and implemented programs to help reduce the trend toward wetland loss and degradation.

Because of growing concerns around water quality and supply, which are key Great Lakes conservation issues, and the role of wetlands in flood attenuation, nutrient cycling and sediment trapping, wetland changes will continue to be monitored closely. Providing accurate useable information to decision-makers from government to private landowners is critical to successful stewardship of the wetland resource.

Comments from the author(s)
Development of improved, accessible, and affordable remote sensing technologies and information, along with concurrent monitoring of other Great Lakes indicators, will aid in implementation and continued monitoring and reporting of this indicator.

The GLCWC database represents an important step in establishing a baseline for monitoring and reporting on Great Lakes coastal wetlands including extent and other indicators. Affordable and accurate remote sensing methodologies are required to complete the baseline and begin monitoring change in wetland area by type in the future. Other GLCWC-guided research efforts are underway to assess the use of various remote sensing technologies in addressing this current limitation. Preliminary results from these efforts indicate the potential of using radar imagery and methods of hybrid change detection for monitoring changes in wetland type and conversion.

The difficult decisions on how to address human-induced stressors causing wetlands loss have been considered for some time. Several organizations and programs continue to work to reverse the trend, though much work remains. A better understanding of wetland functions, through additional research and implementation of biological monitoring within coastal wetlands, will help ensure that wetland quality is maintained in addition to areal extent. An educated public is critical to ensuring that wise decisions about the stewardship of the Great Lakes basin ecosystem are made.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada					X	
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

Acknowledgments
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Laura Bourgeau-Chavez, General Dynamics Advanced Information Systems

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Last Updated

State of the Great Lakes 2009

Climate Change: Ice Duration on the Great Lakes
Indicator #4858

Editor's Note (2009)
This indicator was last updated in 2007. Since that time, re-evaluation of the information presented suggests that the trend would be better represented as Unchanging rather than Deteriorating. Also, this report represents only one indicator relevant to the analysis of climate change in the Great Lakes basin, and extrapolation to generalized conclusions about climate change is not warranted.

Much additional information about climate change and links to supporting web pages are available through:
- *Environment Canada:* http://www.ec.gc.ca/climat-climate/default.asp?lang=En&n=E584B5CF-1 *or* http://www.ec.gc.ca/climat-climate/default.asp?Lang=Fr&n=E584B5CF-1
- *U.S. Environmental Protection Agency:* http://www.epa.gov/climatechange/
- *Great Lakes Information Network :* http://www.great-lakes.net/envt/refs/cchange.html

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating (with respect to climate change)**

Lake-by-Lake Assessment

Individual lake basin assessments were not prepared for this report.

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

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.

basin in the form of snow. This can have an affect on the foraging animals (such as 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 Great 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 were 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 (Fig. 1).

The trends on each of the five Great Lakes show that during this time span the maximum amount of ice forming each year has been decreasing, which correlated to the average ice cover per season observed for the same time duration (Table 1). Between the 1970s and the 1990s there was at least a 10% decline in the maximum ice cover on each lake, nearly 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 (Fig. 2) based on the complete freeze-over date (ice-on date) and the break-up date (ice-off date). 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 (Magnuson *et al*. 2000).

The satellite data used in this analysis can be supplemented by on-the-ground citizen-collected data. The IceWatch program of Environment Canada's Ecological Monitoring and Assessment Network and Nature Canada have citizen scientists collecting ice-on and ice-off dates of lakes throughout the Ontario portion of the Great Lakes basin. These volunteers use the same criteria for ice-on and ice-off as does the satellite data, although the volunteers only collect data for the portion of the lake that is visible from a single vantage point on the shore. The IceWatch program began in 2000 as a continuation of a program run by the Meteorological Service of Canada. Data from this program date back to the 1850s. An analysis of data from this database and the Canadian Ice Database (Canadian Ice Services/Meteorological Service of Canada) showed that ice break-up dates were occurring approximately one day earlier every seven years between 1950 and 2004 for 341 lakes across

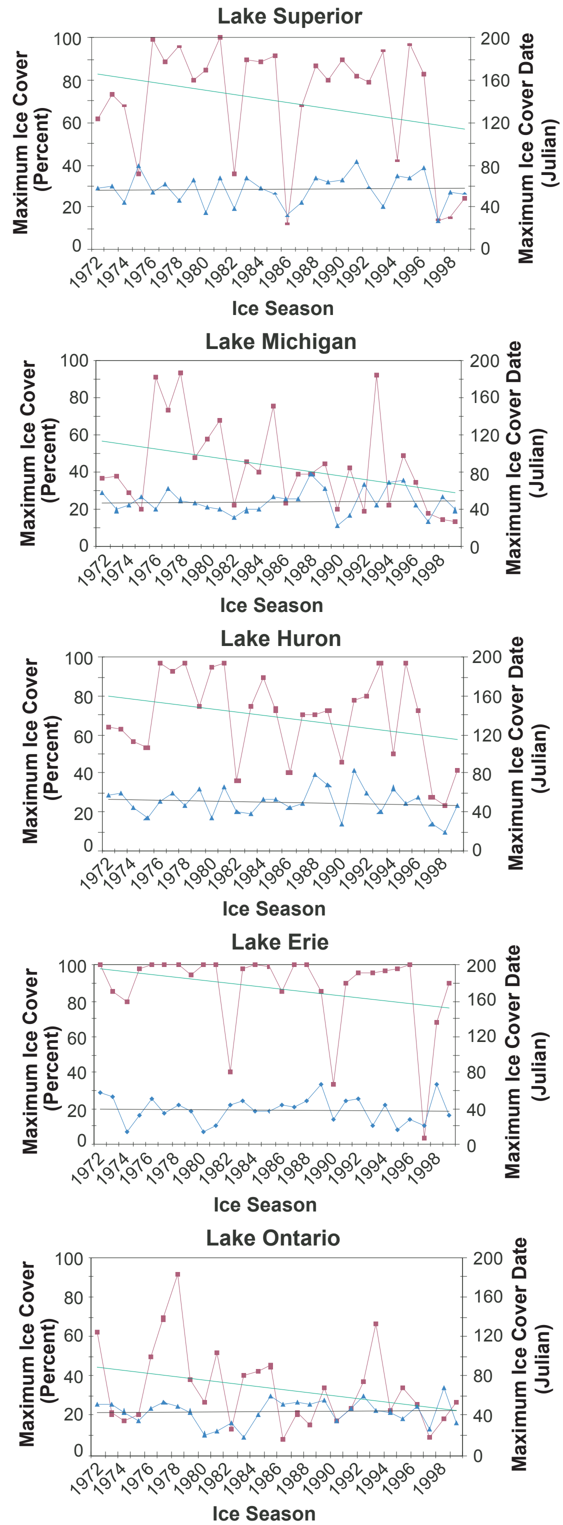

Figure 1. Trends of maximum ice cover and the corresponding date on the Great Lakes, 1972-2000.
The red line represents the percentage of maximum ice cover and the blue line represents the date of maximum ice cover.
Source: National Oceanic and Atmospheric Administration.

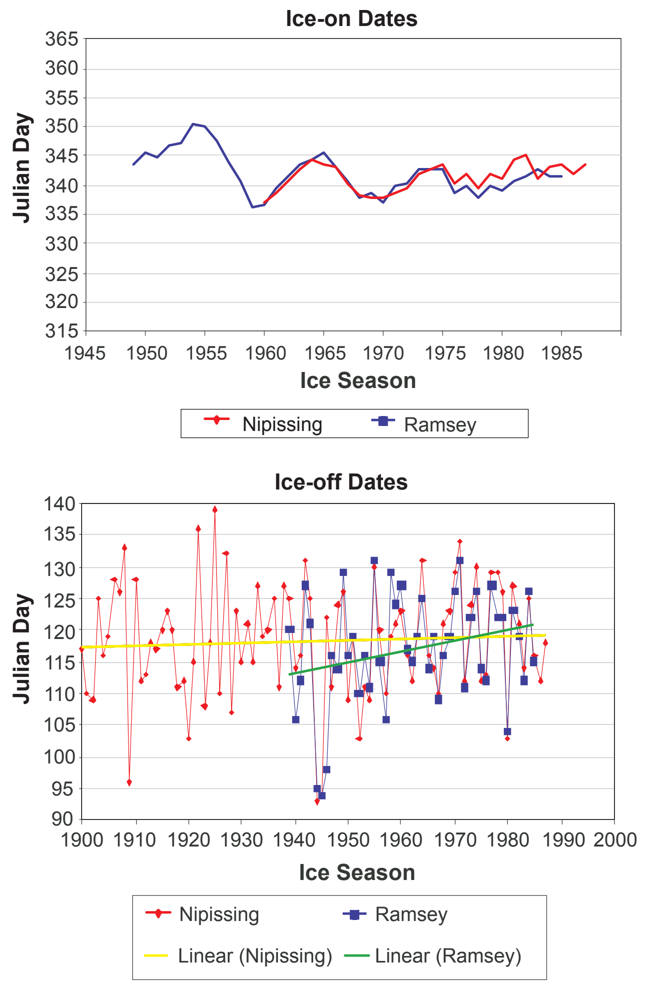

Figure 2. Ice-on and ice-off dates for Lake Nipissing (red line) and Lake Ramsey (blue line).
Data were smoothed using a 5-year moving average.
Source: Climate and Atmospheric Research and Environment Canada.

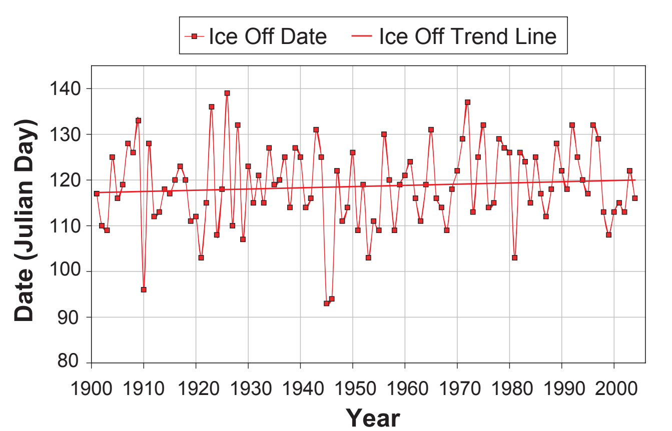

Figure 3. Ice-off dates and trend line from 1900-2000 on Lake Nipissing.
Source: Ecological and Monitoring Assessment Network (EMAN).

Canada (Futter, unpublished data). The data from IceWatch are not as comprehensive as the satellite-collected data, but they do show some trends in the Great Lakes basin. From two sites with almost 100 years of data, Lake Nipissing is shown to be thawing later in the season (Fig. 3). IceWatch data from near Lake Ramsey indicate that lakes have been freezing later over the past 30 years.

Pressures

Based on the results of Figure 1 and Table 1, it seems that ice formation on the Great Lakes should continue to decrease in total cover if the predictions on global atmospheric warming are true. Milder winters will have a drastic effect on how much of the lakes are covered in ice, which in turn, will have an effect on many aquatic and terrestrial ecosystems that rely on lake ice for protection and food acquisition.

Management Implications

Only a small number of data sets were collected and analyzed for this study, so this report is not conclusive. To reach a level of significance that would be considered acceptable, more data on lake ice formation would have to be gathered. While the data for the Great Lakes is easily obtained from 1972 through the present, smaller inland lakes, which may be affected by climate change at a faster rate, should be examined. As much historical information as is available should be obtained. This data could come from IceWatch observers and the IceWatch database from throughout the Great Lakes basin. The more data that are received will increase the statistical significance of the results.

Comments from the author(s)

Increased winter and summer air temperatures appear to be the greatest influence on ice formation. Currently there are global protocols, which are being introduced in order to reduce the emission of greenhouse gases.

It would be convenient for the results to be reported every four to five years (at least for the Great Lakes), and quite possibly a shorter time span for any new inland lake information. It may also be feasible to subdivide the Great Lakes into bays and inlets, etc., in order to get an understanding of what is occurring in nearshore environments.

Acknowledgments

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All data analyzed and charts created by the author.

Sources

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Ice charts obtained from the National Oceanic and Atmospheric Administration (NOAA) and the Canadian Ice Service (CIS).

Data for Lake Nipissing and Lake Ramsey obtained from Walter Skinner, Climate and Atmospheric Research, Environment Canada-Ontario Region.

Last Updated

State of the Great Lakes 2007

Effect of Alteration of Natural Water Level Fluctuations

Indicator #4861

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **The alteration of natural lake level fluctuations in the Great Lakes has been a significant driver of degradation in nearshore/coastal wetland vegetation, with the most marked evidence demonstrated in Lake Ontario. However, data gaps exist and preclude a full assessment of impacts.**

Lake-by-Lake Assessment

Lake Superior
Status: Mixed
Trend: Undetermined
Rationale: Nearshore habitat evaluation efforts continue. Data gaps exist in the assessment of impacts on nearshore/coastal wetland vegetation. The on-going International Upper Great Lakes Study will provide an opportunity to develop an improved understanding of the effects of regulation on lake-level changes.

Lake Michigan
Status: Mixed
Trend: Undetermined
Rationale: The on-going International Upper Great Lakes Study is expected to provide an improved understanding of the effects of regulation on the hydrology of the upper Great Lakes system, including indirect influence from regulation on unregulated lakes and physical changes in St. Clair River.

Lake Huron
Status: Mixed
Trend: Undetermined
Rationale: The on-going International Upper Great Lakes Study is expected to provide an improved understanding of the effects of regulation on the hydrology of the upper Great Lakes system, including indirect influence from regulation on unregulated lakes and physical changes in St. Clair River.

Lake Erie
Status: Mixed
Trend: Undetermined
Rationale: Nearshore habitat evaluation efforts continue in Lake Erie. A general understanding exists regarding the loss of habitat health in nearshore ecosystems in Lake Erie and St. Clair River/Lake St. Clair/Detroit River connecting channels. Quality habitat is present along the Ontario shoreline of Lake St. Clair.

Lake Ontario
Status: Mixed
Trend: Deteriorating
Rationale: There is loss of biodiversity in upper elevations of most wetlands as documented by the Lake Ontario-St. Lawrence River Study. Data gaps exist in the assessment of impacts on nearshore/coastal wetland vegetation for any new regulation plan implemented.

Purpose

- Identify data gaps with respect to assessing responses of vegetation to changes from natural lake level fluctuations over time.
- To address data gaps, formulate goals and measurable objectives for designing and implementing a baseline and monitoring program.
- Coordinate with other SOLEC indicators sharing common goals in protecting other nearshore habitats (e.g., fauna) that are impacted by changes from natural variability on water levels.

Ecosystem Objective

The ecosystem objective is to maintain the diverse array of Great Lakes coastal wetlands by allowing, as closely as possible, the natural seasonal and long-term fluctuations of Great Lakes water levels.

State of the Ecosystem

Summary of the SOLEC 2007 Indicator Report #4861 *Effect of Water Level Fluctuations* (Heaton 2007)

"Background" presented the knowledge that naturally-fluctuating water levels are essential for maintaining a healthy shoreline ecosystem in the Great Lakes. *Effect of Water Level Fluctuations* (Heaton 2007) presented and discussed hydrographs representing reconstructed (Baedke and Thompson 2000) and recorded water level histories from each lake. While natural factors affecting lake level fluctuations were not specified, water level regulation on Lakes Superior and Ontario were cited as anthropogenic influences, with mention of other human-related considerations under "Pressure". The significance of naturally-occurring seasonal and long-term water level fluctuations was illustrated in some detail; however, short-term changes occurring outside the hydrologic cycle were not cited (the subject of short-term water-level changes will be discussed later in this report). "Pressure" identified the following issues: withdrawals or diversions of water from the lakes, regulation of the high and low water levels, and climate change. "Management Implications" highlighted the work in progress of the International Lake Ontario-St. Lawrence River Study Board at the time and cited opportunities available to its Environment/Wetlands Working Group for improving the understanding of ecosystem health throughout the Great Lakes, emphasizing the need for monitoring.

The information presented next in this report is a supplement to the SOLEC 2007 indicator report to support the indicator's purpose.

Background on Great Lakes Water Level Fluctuations

Water level changes in the Great Lakes, including fluctuations that vary on timescales ranging from hours to millennia, are the result of changes in water supplies and storage in the Great Lakes related to natural factors, in combination with anthropogenic influences. The summary below is a general account of the overall factors affecting water levels and a limited discussion on water level history and variability.

The natural factors associated with long-term water level changes in the Great Lakes include the various environmental processes and related components that contribute to inflow to, outflow from, and storage in the system as part of the "Great Lakes water balance" (Neff and Killian 2003) and crustal movement caused by isostatic post-glacial rebound, which occurs at variable rates across the basin (Wilcox *et al*. 2007). Within broad scales, water inflow and outflow are dictated by climatically-induced changes that affect the components of the hydrologic cycle, most importantly: over-lake precipitation; the two main components of stream flow, which are surface water runoff and groundwater discharge to streams entering the lake; and evapotranspiration. The flow characteristics of the outlet/connecting channels are also elements of water inflow/outflow for the purpose of the Great Lakes water balance (Neff and Killian 2003, USGS 2005, Wilcox *et al*. 2007). While the direct flow of surface water runoff to the Great Lakes is considered an insignificant flow component, overland precipitation can be used indirectly to estimate surface water runoff associated with stream flow in areas where stream gauging is incomplete (Neff and Killian 2003). Within the water balance, water storage is a function of changes in water levels and thermal expansion/contraction of water. In the Great Lakes region, groundwater discharge is usually the dominant component of base flow; yet, various human and natural factors also contribute to such flow component (Grannemann and Weaver 1999, Neff and Killian 2003). The 2007 SOLEC indicator report *Base Flow due to Groundwater Discharge* (Piggott *et al*. 2007) recognizes the significant contribution of groundwater discharge to stream flow which, in turn, is critical to maintaining lake levels. The discharge of groundwater directly into the Great Lakes, however, has been typically ignored in water-balance calculations because this flow component represents a small contribution relative to other flows (Grannemann and Weaver 1999, Neff and Killian 2003).

Naturally conforming to the annual hydrologic cycle, seasonal water level changes are driven by weather variations that result in differences in basin water supply associated with over-lake precipitation, stream flow and evapotranspiration during the year (Neff and Killian 2003, USGS 2005, Wilcox *et al*. 2007). Storm surges (also known as wind tides) and seiches are responsible for short-term water level changes (Wilcox *et al*. 2007), which drastically affect water levels without a large change in the volume of water in the Great Lakes. Lasting hours to days, storm surges and seiches displace water within the lake basin (Wilcox *et al*. 2007) due to variations from persistent winds and/or changes in barometric pressure. Effects of seiches are poorly understood, although they can affect zonation of plant communities (Wilcox *et al*. 2007) and create backwater effects on tributaries in nearshore ecosystems (Fenelon and Watson 1993, Greeman 1995). Additionally, a natural phenomenon known as El Niño/La Niña/Southern Oscillation, or (ENSO), has the capacity to alter both weather and climate around the globe and in the United States. Extreme phases associated with this phenomenon, El Niño referring to the warm phase and La Niña representing the cool phase, occur at regular intervals of two-seven years and usually last for one-three years. Effects from La Niña brought record snowfall to Great Lakes in 2008.

The effect of anthropogenic factors such as regulation of outflow and water levels, and dredging and removal of sediment bars along shores (Transport Canada *et al*. 2007) differ from lake to lake (Wilcox *et al*. 2007). Dredging and control structures have had the largest anthropogenic impact on water levels (Wilcox *et al*. 2007) in the system of the Great Lakes and connecting channels. A two-year study of the St. Clair River is expected to evaluate physical changes with implications from dredging and its effect on water levels among other aspects. Diversions of water into and out of the Great Lakes are very small compared to the total volume of water stored in the Great Lakes (Wilcox *et al*. 2007). Similarly, impacts from surface water withdrawals from the lake and groundwater withdrawals from within the basin are small relative to other water outflows. However, they may have implications with regards to climate change. The water balance for Lake Michigan, for example, estimates one cubic meter per second (m^3/s) of water diverted into the lake, 212 m^3/s of surface water withdrawals, 60 m^3/s of groundwater withdrawals, and 170 m^3/s of return flows from users (which is reduced by a flow of 91 m^3/s that is diverted out of the basin at Chicago, Illinois) (Grannemann *et al*. 2000). In the Great Lakes basin in the United States and Canada, total withdrawals related to thermoelectric power generation include 1,350 m^3/s (based on 2002 estimates); however, less than 2% of this estimated value is consumed (lost primarily to evaporation) and the remainder is returned to the Great Lakes (Shaffer and Runkle 2007). Hydroelectric power, transportation and water-based recreation involve nonconsumptive uses in which the entire quantity of water withdrawal is returned to the system (USACE 2000). Refer to the SOLEC indicator report *Water Withdrawals* for further update on this topic (Ross and Czepita 2009). Recent focus on initiatives to study the effects of climate change on the Great Lakes ecosystem will likely facilitate an improved understanding of global scale influences on lake levels (IPCC 2007).

Regulation of water levels on Lake Superior and Lake Ontario at their outlets seeks to lessen high and low levels (Wilcox *et al*. 2007). Lake Superior water levels have been regulated through much of the period of record, which reflects a pre-regulation data span of only 55 years. In its 1914 Order of Approval, the International Joint Commis-sion (IJC) established the International Lake Superior Board of Control, responsible for setting Lake Superior outflows and overseeing the operations of various control works. The regulation plans implemented by the board of control under the 1914 Order of Approval are as follows: the Sabin's Rule, Rule of Curve P-5, Rule of 1949, and Plan SO-901. Plan 1977 was adopted in 1979 under the 1978-1979 Supplementary Orders of Approval, following reexamination of the 1914 Order of Approval. Plan 1977 was replaced by Plan 1977-A, which is the regulation plan currently in place for Lake Superior. By 1921, full control of the outlet had been achieved through a collection of structures that stretched across St. Mary's River. It is important to understand, however, that the levels and flows in Lake Superior are only controlled to a certain extent (Clites and Quinn 2003, IJC 2008a). Lake Superior's range of fluctuation during pre-regulation 1.1 m (3.6 ft) range does not differ greatly from the post-regulation 1.2 m (4.0 ft) range. It was with the appointment of the International St. Lawrence River Board of Control under the Order of Approval of 1952, as amended in 1956, that Lake Ontario water levels became subject to regulation, although no control was put in place until 1960. Plan 12-A-9 established by the 1956 Order of Approval was never implemented. Plan 1958-A was adopted in 1958 and became operational in 1960; revised versions Plan 1958-C and Plan 1958-D became operational in 1962 and 1963, respectively. Plan 1958-D has remained the regulation plan for the Lake On-tario-St. Lawrence River system since 1963. The current approach to regulation, Plan 1958-D with deviations, has allowed temporary flow changes for specific purposes at the discretion of the Board of Control's judgment. In pre-regulated Lake Ontario the range of fluctuations was up to 2.0 m (6.6 ft), a value that has been sustained by Lakes Michigan and Huron in recorded history. Lake Erie has also experienced a wide range of fluctuations during re-corded history, reaching up to 1.9 m (6.2 ft). During post-regulation, the range of fluctuations in Lake Ontario has been reduced to 1.3 m (4.3 ft).

It is widely accepted that the extent of the recorded water level history is insufficient to capture a comprehensive insight into lake level variability, unless examined in correlation with reconstructed water level history such as hydrographs produced by Baedke and Thompson (2000) and reported more recently by Wilcox *et al*. (2007). Rise and fall patterns showing some distinctive degree of periodicity in millennial timescale from reconstructed water level history can be extended into the period of recorded water level history, up to the present, to be able to recognize fluctuations over the long term (USGS 2005, Wilcox *et al*. 2007, Sellinger *et al*. 2007). Water level gauges are maintained by the National Oceanic and Atmospheric Administration (NOAA)'s National Ocean Service in the United States (NOAA 2008a) and by the Canadian Hydrographic Service (CHS) in Canada (CHS 2008). The Detroit District of the U.S. Army Corps of Engineers (USACE) collaborates with NOAA and CHS on the collection, analysis and dissemination of Great Lakes water level data (USACE 2008). As Lake Michigan and Lake Huron are joined at the Straits of Mackinac, they are considered one lake hydrologically. Every 25 to 35 years, NOAA's Geodetic Survey adjusts the datum or elevation reference system used to define water levels within the Great Lakes-St. Lawrence River system to correct for crustal rebound. The current datum, known as the International Great Lakes Datum of 1985 (IGLD 1985), was implemented in January 1992 and replaced the previous system, IGLD 1955. The date, 1985, is the central year of the period 1982-1988 in which water level data were collected for preparing the datum revision under the auspices of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (CCGLBHHD). The CCGLBHHD is comprised of committees and representatives from federal

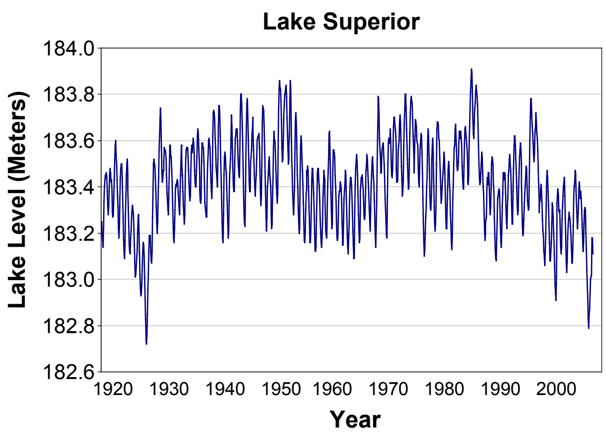

Figure 1. Monthly mean water levels for Lake Superior, 1918–2007. All data are obtained from the Great Lakes Water Level Gauge Network and referenced to the International Great Lakes Datum 1985 (IGLD 1985).
Source: United States Army Corps of Engineers, Detroit District, Great Lakes Hydraulics and Hydrology.

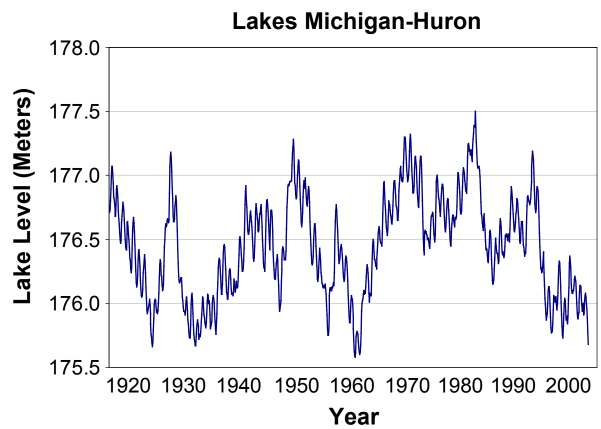

Figure 2. Monthly mean water levels for Lakes Michigan-Huron, 1918–2007. All data are obtained from the Great Lakes Water Level Gauge Network and referenced to the IGLD 1985.
Source: United States Army Corps of Engineers, Detroit District, Great Lakes Hydraulics and Hydrology.

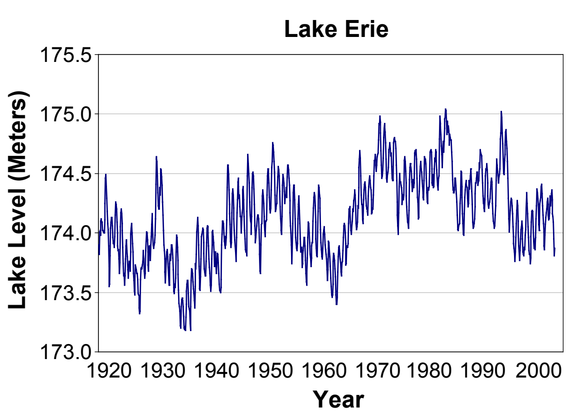

Figure 3. Monthly mean water levels for Lake Erie, 1918–2007. All data are obtained from the Great Lakes Water Level Gauge Network and referenced to the IGLD 1985.
Source: United States Army Corps of Engineers, Detroit District, Great Lakes Hydraulics and Hydrology.

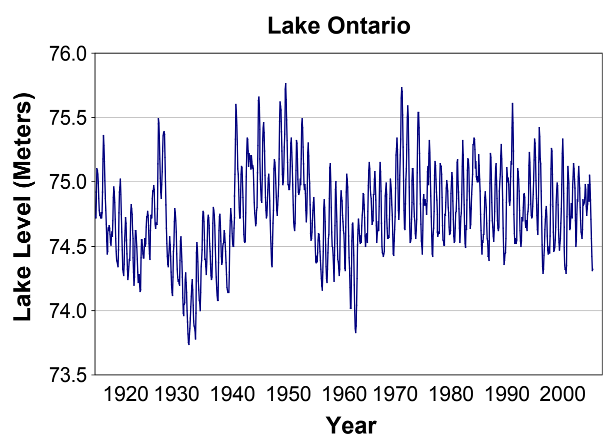

Figure 4. Monthly mean water levels for Lake Ontario, 1918–2007. All data are obtained from the Great Lakes Water Level Gauge Network and referenced to the IGLD 1985.
Source: United States Army Corps of Engineers, Detroit District, Great Lakes Hydraulics and Hydrology.

agencies of the United States and Canada. IGLD 1985 has its zero base at Rimouski, Quebec, near the mouth of the St. Lawrence River, which roughly corresponds to sea level (CCGLBHHD 1992). The next datum revision is targeted for 2015, probably to be implemented several years later (NOAA 2008b and NOAA 2008c). Figures 1 through 4 show lakewide, monthly-mean water levels for Lake Superior, Lakes Michigan-Huron, Lake Erie and Lake Ontario; all water levels are determined based on a network of water level gauges (Table 1) established under the guidance of the CCGLBHHD. Gauge locations were selected based on geography, accessibility and data record to ensure the longest common, complete period of record possible for all the lakes (available from 1918 onward).

Lake Superior Gauges
Duluth, Minnesota; Marquette and Point Iroquois, Michigan; Michipicoten and Thunder Bay, Ontario
Lakes Michigan - Huron Gauges
Harbor Beach, Mackinaw City and Ludington, Michigan; Milwaukee, Wisconsin; Thessalon and Tobermory, Ontario
Lake Erie Gauges
Toledo and Fairport, Ohio; Port Stanley and Port Colborne, Ontario
Lake Ontario Gauges
Rochester and Oswego, New York; Port Weller, Toronto, Cobourg and Kingston, Ontario

Table 1: Great Lakes Water Level Gauge Network. This network has been established under the guidance of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.
Source: United States Army Corps of Engineers, Detroit District, Great Lakes Hydraulics and Hydrology.

Hydrographs for recorded lake level histories for each lake show some similarities of interest (Wilcox *et al*. 2007). Periods of higher lake levels generally occurred in the late 1800s, the late 1920s, the mid-1950s, and from the early 1970s to mid-1980s. Pronounced low lake levels occurred in the mid-1920s, the mid-1930s and the mid-1960s (Wilcox *et al*. 2007), beginning to decline again in 1998 (Sellinger *et al*. 2007). Water levels on Lakes Michigan and Huron have been extremely low since 2000, and Lake Superior was also low in 2007 (Wilcox *et al*. 2007). Some of those extreme levels, especially low, were muted in Lakes Superior and Ontario after inception of regulation in 1914 and 1960, respectively (Wilcox *et al*. 2007). The range of fluctuations and the cyclic pattern of high and low levels on Lake Superior have not been altered as dramatically as on Lake Ontario since both lakes became regulated. Since 1930, however, low lake levels have been consistently higher on regulated Lake Superior as compared to lower levels on other unregulated lakes, indicating a shift to fluctuations that are more limited in range in the case of Lake Superior (Wilcox *et al*. 2007).

It should be noted that the summary presented represents a simplified discussion on the natural and human-induced factors affecting natural water level fluctuations, along with a brief account of long-established database efforts between the Unites States and Canada. Future indicator reports will likely provide a more detailed update on the knowledge of hydroclimatic forces driving the water balance for the Great Lakes. There will be opportunities for exploring in more detail the relationships between hydrologic parameters (e.g., precipitation, evapotranspiration, surface water runoff and groundwater discharge) and communicating findings from past and present hydrologic modeling efforts for the Great Lakes. Future discussions will likely elaborate further on global-scale effects, such as climate change and sunspot periodicity.

Status of Effect of Alteration of Natural Water Level Fluctuations in the Great Lakes

SOLEC 2007 identified the shoreline ecosystems, especially coastal wetlands, as dependant upon water level fluctuations to develop habitat value. Background papers from SOLEC 2007 identified coastal wetlands (including embayments and islands), the lower reaches of all Great Lakes tributaries, and the connecting channels (Edsall and Charlton 1997) as components of nearshore ecosystems.

Alteration of natural lake level fluctuations has been equally recognized as a stressor affecting other ecosystem elements (among them shoreline movement, stabilization of sand dunes, fish access to spawning habitat, and availability of waterfowl habitat and nesting areas) as well as recreation, water consumption and other human activities in the Great Lakes. This indicator will limit its focus to the effects on nearshore vegetation, based on earlier consensus as part of indicator development. However, this report seeks to point out the need to gain a holistic understanding of the effects of changes attributed to natural variability on the diversity of habitat associated with nearshore ecosystems (e.g., fauna habitat from wetlands). Another relevant consideration is the cumulative effect that other stressors may have on nearshore/coastal wetland vegetation (e.g., degradation due to presence of water and sediment contamination, impact from sediment loading, and introduction of non-native species). For example, the 2007 SOLEC indicator report *Coastal Wetland Plant Community Health* identifies several pressures that lead to degradation of coastal wetlands, among them agriculture, coastal manipulation, and other human development scenarios (Albert 2007). Additionally, the importance of climate change has been clearly recognized (IPCC 2007). Most recent updates to the Binational Partnership for Lake Huron and the Lakewide Management Plan (LAMP) for Lakes Superior, Michigan, Erie and Ontario have expressed the need to integrate climate change considerations into decision making.

Four past and present major efforts have been undertaken to address the assessment of coastal/inland wetlands in relation to ecosystem health (Paul Bertram, U.S. EPA GLNPO, personal communication, June 2008). These efforts, some of which have a strict focus on the nearhsore, include the National Monitoring Network and its Lake Michigan Pilot Study (USGS 2008); the Great Lakes Environmental Indicators Project (U.S. EPA 2006); the National Coastal Conditions Assessment (U.S. EPA 2008f); and the wetland inventory and classification effort completed by the Great Lakes Coastal Wetlands Consortium (GLCWC 2003, GLCWC 2004), followed by its recently developed Great Lakes Coastal Wetlands Monitoring Plan (GLCWC 2008). These efforts are expected to make progress toward addressing data gaps in the nearshore. Additional evidence has been gathered on species' adaptability under changing water level fluctuation conditions. Wilcox and Nichols (2008) document the ability of some plant species to recolonize exposed areas along the shore during periods of decreased water levels. Further gaps can be addressed in areas where limited knowledge exists, such as the effect of low lake water levels on the Great Lakes island habitats (USACE 2005). The 2007 SOLEC indicator report *Area, Quality and Protection of Special Lakeshore Communities - Islands* presented the first detailed binational map and database of Great Lakes islands, while calling attention to indicator needs (Cuthbert *et al*. 2007). Similarly, the Conservation Blueprint of the Great Lakes (TNC 2008) which was recently issued by the Nature Conservancy may prove to be a useful tool to help define indicator needs. It would be valuable, however, to integrate in some manner these efforts with any future implementation of a baseline and monitoring program related to this indicator. Noteworthy are the examples of coastal wetlands in the Great Lakes that have been recognized internationally.

For further details, refer to summaries below for each of the Great Lakes.

Summary of Effects by Lake

Lake Superior

Recent experiences from a restoration project in Nipigon River point out to the need for an improved understanding of the interactions between surface water and groundwater locally. At Nipigon River, springs provide a source of water supply for spawning habitat in the lower portion of the tributary (U.S. EPA 2008a). A conservation plan will be developed to protect critical lake and tributary habitat (U.S. EPA 2008a). Also, input from seiches may play a role in the distribution of organic matter in coastal wetlands as seen in some areas in Lake Superior (Trebitz *et al*. 2005).

In October 2007, the Government of Canada announced the creation of the country's newest National Marine Conservation Area (NMCA). More than 10,000 km^2 (3,861 mi^2) of Lake Superior, including the lakebed, islands, and north shorelands within the NMCA boundaries, make up the largest freshwater marine protected area in the world. Protected areas such as NMCAs may be valuable for drawing effect-response relationships to support baseline/monitoring strategies.

In February 2007, the IJC appointed the International Upper Great Lakes Study Board to conduct a five-year study to evaluate options for regulation of Lake Superior outflows and water levels in a manner that benefits affected interests in the upper Great Lakes. The study board is expected to integrate all relevant information needed to evaluate the system involving Lakes Superior, Michigan, Huron, and Erie, and their connecting channels (St. Mary's River, St. Clair River, Lake St. Clair, Detroit River and Niagara River), while proceeding with the investigation of physical changes in the St. Clair River on a faster two-year track. Conditions in the St. Clair River will be evaluated as one factor possibly affecting water levels and flows on Lakes Huron and Michigan. The study board will also evaluate whether remediation measures may be warranted in the St. Clair River.

Lake Michigan

Since LAMP 2000, the Lake Michigan LAMP has presented a crosswalk between the SOLEC indicators and the LAMP goals, demonstrating a strong alignment. As part of the Great Lakes Basin Study under its National Water Availability and Use Program, the USGS is developing a groundwater-flow model effort for the Lake Michigan subbasin to assess water availability and use. This effort will include simulation techniques addressing the interactions of groundwater and surface water at the appropriate scale (USGS 2005). Moreover, beginning with Lake Michigan in 2008, U.S. EPA is initiating additional nearshore monitoring using a towed sensor package known as "TRIAXUS" that will help provide a three-dimensional characterization of basic physical, chemical and biological aspects of the nearshore, as well as side scan sonar mapping of underwater habitat (U.S. EPA 2008b). These studies will assist in expanding the understanding of habitat in nearshore areas. Thus, the results from these studies will be useful for developing further knowledge on the effects of alteration of natural water level fluctuations on nearshore/coastal wetland vegetation.

The Great Lakes Coastal Wetland Consortium identified 800 coastal wetlands in Lake Michigan (U.S. EPA 2008c). The health of these wetlands has not been assessed relative to this indicator. Historical patterns in the nearshore include changes in water levels from seiches. Effects from seiches, for example, have been observed in the Grand Calumet River/Indiana Harbor Canal from Indiana, although generally with amplitudes smaller than the maximum of approximately 0.9 m (3.0 ft) observed in other parts of Lake Michigan. Fenelon and Watson (1993) and Greeman (1995) report that during the record-high Lake Michigan levels of 1985-1987, backwater effects were observed as much as 18 km (11.2 miles) upstream on the East Branch of the Grand Calumet River and 11 km (6.8 miles) upstream on the West Branch.

The Lake Michigan LAMP identifies the expectation that an increase in evaporation rates due to decline in winter ice coverage in the Great Lakes will likely result in lowering of lake levels, calling attention to the need for continued coordination between the LAMP and SOLEC indicators on this issue.

Refer to above discussion under Lake Superior regarding the Five-year International Upper Great Lakes Study.

Lake Huron
The Great Lakes Coastal Wetland Consortium identified 1,255 coastal wetlands in Lake Huron, which along with identified Ontario wetlands, represent the greatest amount of coastal wetlands relative to other Great Lakes on the Canadian shoreline (U.S. EPA 2008c). The health of these wetlands has not been assessed relative to this indicator.

Refer to above discussion under Lake Superior regarding the International Upper Great Lakes Study.

Lake Erie
Wetland losses have been more pronounced in the Western basin of Lake Erie and the connecting channels as a result of the permanent flooding caused by isostatic rebound. Within its natural system, Lake Erie is most susceptible to storm surges and seiches compared to the rest of the lakes, due to its east-west orientation with its generally shallow Western basin in an area of prevailing westerly winds (USACE 2000). Historically, extreme seiches have been recorded in Lake Erie with amplitudes as large as five metres (16.4 ft).

Along with the lake-influenced portion of the Great Lakes tributaries and the rest of the connecting channels, Lake St. Clair is considered part of the nearshore waters because of its shallow depth which precludes the presence of vertical thermal stratification (Edsall and Charlton 1997, U.S. EPA 2008d). Wetlands and agriculture dominate along the Ontario shoreline of Lake St. Clair (U.S. EPA 2004).

The Long Point complex and Point Pelee on the north shore of Lake Erie and the National Wildlife Area on Lake St. Clair are ecosystems being recognized on a global scale because of their outstanding biological significance. Long Point has also been designated a United Nations Environmental Scientific Collaboration Organization (UNESCO) Biosphere Reserve (UNESCO 2008).

The Lake Erie LAMP Indicator Task Group has developed an indicator matrix that spreads across five habitat zones, among them coastal wetlands and nearshore. This effort will build upon work from the Great Lakes Environmental Indicator Project (U.S. EPA 2006). Additionally, an integrated habitat classification system and binational map will be developed for the Lake Erie basin (U.S. EPA 2008d).

Refer to above discussion under Lake Superior regarding the International Upper Great Lakes Study.

Lake Ontario
Cattail (*Typha* sp.) has replaced more diverse habitat at upper elevations in nearly all wetlands in Lake Ontario (Wilcox *et al*. 2005, Wilcox *et al*. 2007, Wilcox *et al*. 2008, U.S. EPA 2008e) as a result of the permanent flooding caused by the creation of the St. Lawrence Seaway.

In 2000, in the face of growing dissatisfaction from some interests and the lack of a comprehensive assessment of regulation for about half a century, the International Lake Ontario-St. Lawrence River Study Board initiated a five-year study for the IJC, by which it was appointed. At the time of SOLEC 2007, the study was underway to evaluate the procedures and criteria used to regulate the outflows of Lake Ontario and the management of water levels of the lake and the St. Lawrence River, taking into account the impact of regulation on affected interests. To meet its objective, the study board gathered and, as warranted, developed the technical information necessary for gaining an improved understanding of the impact of regulation on the system. For example, wetland predictive models were constructed to assist in predicting the responses of wetland plant communities to the proposed new water level regulation plans (Wilcox and Xie 2007). The predictive model was also incorporated into faunal predictive models (LimnoTech 2005). Among the equally-considered interests in the IJC study were coastal properties; commercial navigation; domestic, industrial and municipal water uses; the environment; hydroelectric power; and recreational boating and tourism. Before concluding its assessment, the study board presented three candidate regulation plans, Plans A, B and D, holding discussion at public meetings in summer 2005.

Based on public input, the study board developed new plans (Plans A+, B+ and D+), which were incorporated into its final report to the IJC in May 2006, along with an invitation for public comments. The IJC subsequently consulted some of the study experts to develop the two additional plans: D+ variant, called Plan 2007, and a B+ variant. Upon deliberation and consideration of public comments, the IJC has released a proposed new Order of Approval and Plan 2007, with an invitation for public comment until July 11, 2008. In the IJC's view, Plan 2007 would provide additional environmental benefits (e.g., greater wetland diversity along the shores of Lake Ontario) without significant changes to the level of protection and benefits that are currently being provided to other interests in the current plan, Plan 1958-D with deviations. An element of the plan being highlighted as an environmental advantage is the inducement of a purported significant difference in hydrology as compared to current water level regulation, allowing a decline in water levels greater than what Lake Ontario has been experiencing during dryer summers for a typical 20-30 year period. As pointed out by the IJC, this decline in water levels would be expected to provide opportunities for more diverse habitat. However, great public controversy exists over the proposed plan because of competing stakeholder interests. Environmental groups consider that the IJC has failed the people and the environment by proposing Plan 2007 (Caddick *et al*. 2008). Plan 2007 also reduces lake levels from late autumn through early spring even more that the current plan and would negatively impact muskrat over-wintering and fish that spawn in wetlands in spring (Douglas A. Wilcox, USGS, personal communication, July 2008).

Pressures

An increasingly prominent area where knowledge is limited with respect to alteration of natural water level fluctuations is climate change.

In the view of environmental groups, Plan 2007 calls for regulation that does not allow sufficient natural variability in water levels for improved wetland biodiversity, nor does it favor access to fish spawning grounds during the breeding season, and enhancement of connectivity between aquatic and terrestrial habitats essential for wintering mammals in the wetland.

A final peer-reviewed report on the St. Clair River study is expected in June 2009. The remaining scope of the International Upper Great Lakes Study would be completed by 2013.

Management Implications

The upcoming 50th anniversary of the opening of the St. Lawrence Seaway brings more into focus the challenges for balancing public interest on the Lake Ontario-St. Lawrence River system while ensuring adequate protection of the Great Lakes ecosystem, more critically the nearshore.

Groundwater that discharges to tributaries and later flows toward and into the Great Lakes affects stream flow on a longer time scale than surface water runoff. This consideration adds complexity to the efforts to help define water availability and its relation to changes in lake levels; this could be especially important under certain climate change scenarios. Similarly, water diversions and withdrawals may have implications with respect to climate change over time.

Declining water levels may have an effect on water quality (e.g., increased loading of nutrients, contaminants and sediment) which, in turn, may aggravate stress conditions in nearshore/coastal wetland vegetation.

Wetland predictive models prepared over the Lake Ontario and St. Lawrence River shoreline can be expanded to the rest of the Great Lakes as a desired approach in terms of consistency and continuity (refer to Summary of Effects by Lake). Similarly, coordination can be fostered among ongoing wetland assessment efforts, such as the GLCWC's Great Lakes Coastal Wetland Monitoring Plan (GLCWC 2003, 2004), the IJC's proposed Adaptive Management for the Lake Ontario-St. Lawrence River System

(IJC 2008b), and the development of a habitat classification system and binational map supporting the Lake Erie LAMP (U.S. EPA 2008d). As expressed earlier, it would be desirable to align under a comprehensive set of goals and objectives this indicator project and other efforts across habitats in the nearshore ecosystem that may have the task of assessing effects from changes in water levels. Generally, piecemeal approaches may not facilitate a holistic understanding of issues, leading to duplication of effort that interferes with adaptive management. U.S. EPA requires the use of a systematic planning process for collection of environmental data and prefers that most project planning be accomplished using the DQO process (U.S. EPA 2000).

With the expected change in regulations for Lakes Ontario and, possibly, Lake Superior, the ability to effectively monitor responses of nearshore/coastal wetland vegetation will be essential for confirming that new plans, when implemented, represent an improvement over the current regulations. The outline below attempts to pose some of the design questions for a baseline and monitoring program to assist with further development of this indicator.

Identification of data gaps: A suggested conceptual model would establish stressor-receptor relationship(s). Such relationship(s) would identify "alteration of natural water-level fluctuations" as the stressor; "vegetation" as the receptor, specifically coastal wetlands and other plant habitat in nearshore ecosystems; and "degradation of vegetation" as a measurable effect/response.

Goals, objectives and measures: Some key planning considerations would include using quality assurance/quality control principles to ensure that the data are scientifically defensible; adopting consistent, standardized methods; and defining short- and long-term objectives among others.

Baseline and monitoring: Baseline conditions should be established to monitor changes in vegetation. Although challenging, building "categories" of monitoring sites and corresponding reference sites would facilitate stressor characterization, to the extent possible, with emphasis on: regulated and unregulated conditions; evolving regulation; indirect influence from regulation on unregulated lakes; other multi-factors contributing to changes from natural variability (e.g., changes in bathymetry caused by dredging); other stressors (e.g., presence of contamination); and global scale climate change. Select baseline and monitoring parameters that are useful in understanding effect on vegetation and discerning trends are: updated, recorded water level history; plant species assemblage; physical expression of stressor (e.g., magnitude of exposed shoreline); and biodiversity, among others.

Comments from the author(s)

In light of the recently initiated International Upper Great Lakes Study, the lake-by-lake assessment should include the St. Clair River/Lake St. Clair/Detroit River connecting channels as a separate category (e.g., connecting channel assessment) to accommodate anticipated complexity in the future. For the purpose of this report, the mentioned con-necting channels are included in the assessment of Lake Erie.

The title of this indicator was revised as follows: **Effects of Alteration of Natural Water Level Fluctuations**. The proposed revised title would be more informative for the public and would more closely reflect the indicator's purpose. An alternate title enhancement would be to identify the ecosystem that is relevant to this indicator by adding a term that would capture the different lake-effect habitat zones in the Great Lakes. An example of a suggestion would be: **Effects of Alteration of Natural Water Level Fluctuations in Nearshore Ecosystems**. The need for consistency with the **Ecosystem Objective** is also noted (see also comment below suggesting the need for clarification of terminology). Moreover, the **Purpose** of this indicator was updated, but may need further refinement as more progress on indicator development is made.

Some clarification would be helpful regarding what may be the most adequate terminology to describe the ecosystem in association with the plant habitat that this indicator is protecting (e.g., coastal wetlands, nearshore aquatic). For example, the SOLEC indicator category assessment for "Coastal Zones and Aquatic Habitats" links nearshore aquatic and coastal wetlands to coastal zones as a broader category. Refer to this indicator's discussion under **State of the Ecosystem**.

Acknowledgments

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Coastal Wetland Plant Communities

Indicator #4862

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **The status of the coastal wetland plant community in the Great Lakes is mixed because Lake Superior and Lake Ontario have individual wetlands plant communities that have a good status. Lake Michigan, Lake Huron, and Lake Erie are all listed with a fair status of their coastal wetland plant community health.**

Lake-by-Lake Assessment

Lake Superior
Status: Mixed
Trend: Undetermined
Rationale: Degradation around major urban areas. Coastal wetlands plants in Lake Superior generally have a good status.

Lake Michigan
Status: Fair
Trend: Undetermined
Rationale: High quality wetlands in the northern part of the lake. Lakes Michigan's northern open embayments and protected embayment are higher quality compared to the coastal wetlands in the drowned river mouth.

Lake Huron
Status: Fair
Trend: Undetermined
Rationale: Plowing, raking and mowing on Saginaw Bay wetland during low water causing degradation. Northern wetlands are higher quality. Lake Huron's northern protected embayments and open embayments generally have fair to good status with individual wetlands having good status. However, in Saginaw Bay the open embayment have poor to fair status.

Lake Erie
Status: Fair
Trend: Deteriorating
Rationale: Generally poor on U.S. shore with some restoration at Metzger Marsh Ohio. Presque Isle, Pennsylvania and Long Point, Ontario have high quality wetlands. Lake Erie's open and sand-spit embayments have a fair status. The lake is also classified as deteriorating based on historical data from 1975.

Lake Ontario
Status: Poor
Trend: Unchanging
Rationale: Degraded by nutrient loading and water level control. Some scattered Canadian wetlands of higher quality. Lake Ontario's barrier beach lagoons have higher quality than the drowned river mouths and the protected embayments. However, individual coastal wetlands in the protected embayments have good status.

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 and non-native plants species that have low levels of coverage. Significant wetland areas in the Great Lakes system that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated (Annex 13 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

State of the Ecosystem

The conditions of the plant community in coastal wetlands naturally differ across the Great Lakes basin, due to differences in geomorphic and climatic conditions. The characteristic size and plant diversity of coastal wetlands vary by wetland type, lake, and latitude; in this document these differences will be described broadly as "regional wetland types."

<u>Regional Wetland Types</u>

Coastal wetlands are divided into three main categories based on the hydrology of the area. Lacustrine wetlands are connected to the Great Lakes, and they are largely impacted by fluctuations in lake levels. Riverine wetlands occur near rivers that are found in the Great Lakes basin. The water quality, flow rate and sediment input are controlled in large part by their individual drainages. However, water levels and fluvial processes in these wetlands are influenced by coastal processes because lake waters flood back into the lower portions of the drainage system (Albert *et al*. 2006). The last type of coastal wetlands is barrier protected. Barrier protected wetlands are derived from coastal processes that separate the wetland from the Great Lakes by barrier beaches. All coastal wetlands contain different zones (swamp, meadow, emergent, submergent), some of which may be absent in certain types of wetlands. Great Lakes wetlands were classified and mapped in 2004 (see http://glc.org/wetlands/inventory.html; United States coastal wetlands inventory map (http://glc.org/wetlands/us_mapping.html) and Canada coastal wetland inventory map (http://glc.org/wetlands/can_mapping.html).

<u>Lake Variations</u>

Physical properties such as the type of shoreline and chemical and physical water quality parameters vary between the Great Lakes. The variation of nutrient levels creates a north to south gradient, and nutrient levels also increase in lake basins further to the east including Lake Erie, Lake Ontario, and the upper St. Lawrence River. Lake Superior is the most distinct great lake due to its low alkalinity and prevalence of bedrock shoreline.

<u>Differences in Latitude</u>

Latitudinal variations result in different climatic conditions based on the location of the coastal wetlands. Temperature differences between the north and south lead to differences in the species of plants found in coastal wetlands. The southern portion of the Great Lakes also has increased agricultural activity along the shorelines, resulting in increased nutrient loads, 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:

<u>Water level fluctuation</u>

Great Lakes water levels fluctuate greatly from year to year. 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.

<u>Lake-wide alterations</u>

For the southern lakes, most wetlands have been dramatically altered by both intensive agriculture and urban development of the shoreline. Alterations of coastal wetlands especially in the wet meadow and upper emergent zones will lead to drier conditions which may allow invasive species to establish.

There are several hundred species of plants that occur within coastal wetlands. To evaluate the status of wetlands using plants as indicators, several different plant metrics have been suggested. These are discussed briefly here.

Invasive plant cover

The invasive plant cover for an entire site and all coastal wetlands zones including wet meadows, dry emergent, flooded emergent and submergent zones that are considered high quality should not have any invasive plants present. For low quality coastal wetlands all zones are expected to have 25% to 50% cover of invasive plants. Invasive plant cover that is more than 50% is considered to be very low quality (Albert 2008). Invasive plant cover includes both native and non-native invasive plants.

Invasive frequency

The invasive frequency is measured similar to invasive plant cover. Invasive plants are expected to be absent in all coastal wetland zones for a coastal wetland to be considered a high quality coastal wetland. When invasive frequency is considered low to very low quality, invasive plants are present in 25% to more than 50% of the coastal wetland (Albert 2008). Invasive frequency includes both native and non-native invasive plants.

Mean conservatism (native species)

Conservatism indices were developed using the Floristic Quality Assessment (FQA) program. The mean conservatism is an index that measures the specificity of a particular species of plant to a specific habitat (Albert 2008). The mean conservatism index also evaluates the intactness of coastal wetlands, which is based on all of the plant species in the wetland. A species is considered conservative if it only grows in a specific, high quality environment. Plant species that are ubiquitous receive a low conservatism score (0), however plant species that are rare and only found in specific habitats are assigned a high conservatism score (10) (Swink and Wilhelm 1994). The mean conservatism index includes all of the species found in a habitat.

Mean conservatism ratios may also be calculated. The ratio is derived by taking the mean conservatism index for all species present divided by the mean conservatism index for native species. Mean conservatism ratios that are less than 0.79 are expected to represent large numbers of exotic species present with degraded conditions. Mean conservatism ratios that are 0.8 and above represent medium to high quality conservatism with many native species present (Albert 2008).

Lake Assessment Scale for Mean Conservatism Scores	
Good	6.0 and above
Fair	3.0 - 5.9
Poor	0.0 - 2.9
Mixed	Combination of two categories

Data were collected and interpreted from Table 3-4 written by Albert 2008.

The total marsh in Lake Superior appears to have the highest quality wetlands when compared to the other lakes with a 6.4 conservatism index. Lake Michigan and Lake Huron have very similar total marsh conservatism indices ranging from 4.5 to 5.6. Lake Erie has a fair conservatism index ranging from 3.1 to 4.5. However, compared to historic ratings, the coastal wetlands are deteriorating. Lastly, Lake Ontario has a fair conservatism index with a range consisting of 3.9 to 5.7. Overall, a majority of the lakes fall into the fair quality of coastal wetland based on the conservatism index.

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 lakewide nearshore 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. The turbidity of the southern Great Lakes, however, 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 reeds in many wetlands, especially in Lake St. Clair and southern Lake Huron, including Saginaw Bay. As water levels rise, the response of reeds 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 reeds, reed canary grass, and purple loosestrife have become 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 plants may be able to establish themselves when water level changes create appropriate sediment conditions.

Pressures

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 zones 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 wetlands, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increasing nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

Residential shoreline development

Residential development has altered many coastal wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the 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 via 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 allow many of the most damaging aquatic weeds to out-compete native species. Most of the most damaging 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 most damaging non-native species has been Asian carp; these species' mating and feeding activities can result in loss of submergent vegetation in shallow marsh waters.

Management Implications

Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on basinwide scale has net yet occurred. Implementations of a long term coastal wetland monitoring program is pending, however support for this program is needed by resource managers throughout the basin.

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 Cootes Paradise, Oshawa Second, and Metzger 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, thereby reducing algal blooms. However, even slight levels of nutrient enrichment can 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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			
Clarifying Notes: Data was collected by the Great Lakes Coastal Wetlands Consortium using the Great Lakes Coastal Wetland Monitoring Plan. There has been a lot of sampling, with most of the larger marshes in all of the Great Lakes being sampled. The only exception is Georgian Bay, where the sampling has been spottier and the overall development of indicators less detailed.						

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Land Cover Adjacent to Coastal Wetlands

Indicator #4863

Note: This is a progress report towards implementation of this indicator.

Overall Assessment

Status: **Not Fully Assessed**
Trend: **Undetermined**
Rationale: **The status and trends are currently under investigation and proposed for additional investigation for the full basin. Although other results exist for Canada, "Land Cover Adjacent to Coastal Wetlands" results are currently unavailable for Canada.**

Lake-by-Lake Assessment

Each individual lake was described as having a not assessed status and an undetermined trend. The status and trends are currently under investigation and proposed for additional investigation in each Lake Basin.

Purpose

- To assess the basin-wide presence, location, and/or spatial extent of land cover in close proximity to coastal wetlands
- To infer the condition of coastal wetlands as a function of adjacent land cover

Ecosystem Objective

Restore and maintain the ecological (i.e., hydrologic and biogeochemical) functions of Great Lakes coastal wetlands. Presence, wetland-proximity, and/or spatial extent of land cover should be such that the hydrologic and biogeochemical functions of wetlands continue.

State of the Ecosystem

Background

The state of the Great Lakes Ecosystem (i.e., the sum of ecological functions for the full Great Lakes basin) is currently under investigation and proposed for additional investigation (Lopez *et al*. 2006). Differences in the regional status of "Habitat Adjacent to Coastal Wetlands" can be determined using the existing data (see Pressures), but the results are preliminary and observations are not conclusive. Nor can the regional trends be extrapolated to determine the state of the ecosystem as a whole.

Relevant coastal areas in the Great Lakes basin have been mapped to assess the presence and proximity of general land cover in the vicinity of wetlands using satellite remote-sensing data and geographic information systems (GIS), providing a broad scale measure of land cover in the context of habitat suitability and habitat vulnerability for a variety of plant and animal species. For example, upland grassland and/or upland forest areas adjacent to wetlands may be important areas for forage, cover, or reproduction for organisms. Depending upon the particular physiological and sociobiological requirements of the different organisms, the wetland-adjacent land cover extent (e.g., the width or total area of the upland area around the wetland) may be used to describe the potential for suitable habitat or the vulnerability of these areas of habitat to loss or degradation. Although other related Great Lakes indicators are described or proposed to include Canadian data at a broad scale (Lopez *et al*. 2006), basin-wide "Land Cover Adjacent to Coastal Wetlands" results are currently unavailable for Canada.

Status of Land Cover Adjacent to Coastal Wetlands

Percent forest adjacent to wetlands

The amount of forest land cover on the periphery of wetlands may indicate the amount of upland wooded habitat for organisms that may travel relatively short distances to and from nearby forested areas and wetland areas for breeding, water, forage, or shelter. Also, the affects of runoff on wetlands from nearby areas (e.g., nearby agricultural land) may be ameliorated by biogeochemical processes that occur in the forests on the periphery of the wetland. For example, forest vegetation may contribute to the uptake, accumulation, and transformation of chemical constituents in runoff. Broad-scale approaches to assessing percentage of forest directly adjacent to wetlands may be calculated by summing the total area of forest land cover directly adjacent to wetland regions in a reporting unit (e.g., an Ecoregion, a watershed, or a state) and dividing by wetland total area in the reporting unit. This calculation ignores those upland areas of forest outside of the adjacent "buffer zone" for wetlands within each reporting unit. Other buffer distances may be appropriate for other habitat analyses, depending on the type of organism. For runoff analyses, the chemical constituent(s), flow dynamics, soil conditions, position of wetland in the landscape, and other landscape characteristics should be carefully considered. Coastal wetland areas may be generally assessed by calculating forest wetland-adjacency in specifically targeted coastal wetlands of interest, by targeting narrow coastal areas such as areas within 1 km (0.62 miles) of the lake shoreline (Fig. 1), or by targeting all wetlands in a specific inland and coastal region of the historical lake plain (Fig. 2).

Percent grassland adjacent to wetlands

The amount of grassland on the periphery of wetlands may indicate the amount of upland herbaceous plant habitat for organisms that might travel relatively short distances to and from nearby upland grassland and wetland areas for breeding, water, forage, or shelter. As with forested areas, the affect of runoff on wetlands from areas nearby (e.g., agricultural) land may be ameliorated by biogeochemical processes that occur in herbaceous areas that are on the periphery of the wetland. For example, herbaceous vegetation stabilizes soils and may reduce erosional soil loss to nearby wetlands and other surface water bodies. As with forest calculations, broad-scale approaches to assessing percentage of grassland directly adjacent to wetlands may be calculated by summing the total area of grassland directly adjacent to wetland regions in a reporting unit. Other buffer distances may be more appropriate for habitat analyses, depending on the type of organism. For runoff analyses, the chemical constituent(s), flow dynamics, soil conditions, position of wetland in the landscape, and other landscape characteristics should be carefully considered. Coastal wetland areas may be generally assessed by calculating grassland wetland-adjacency in specifically targeted coastal wetlands of interest; by targeting narrow coastal areas such as areas within 1 km of the lake shoreline (Fig. 3), or by targeting all

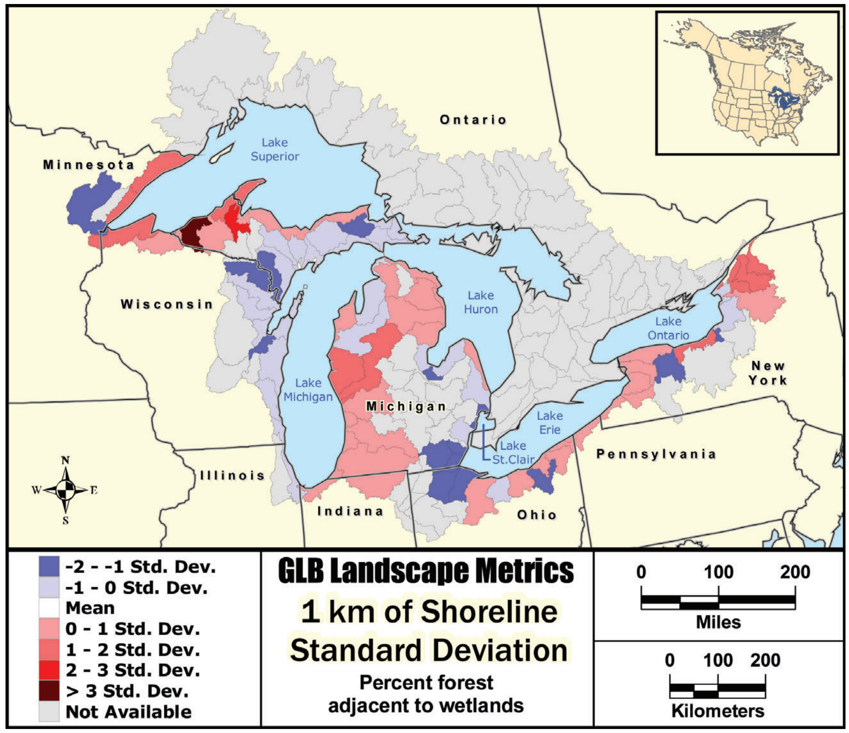

Figure 1. Percent forest adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 1 km of shoreline; data are reported as standard deviations from the mean.
Source: Lopez *et al*. 2006.

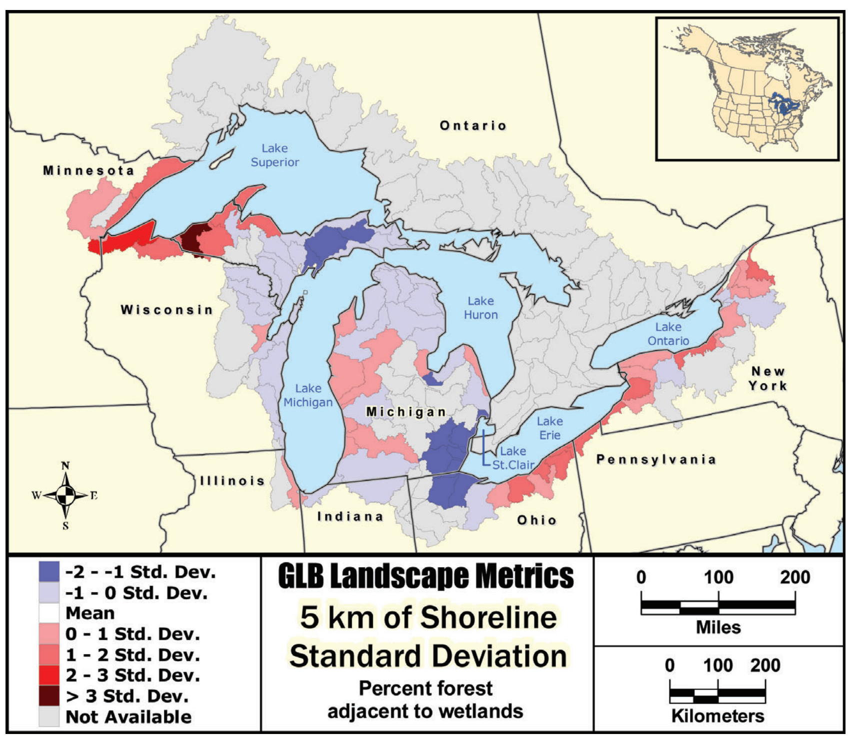

Figure 2. Percent forest adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 5 km of shoreline; data are reported as standard deviations from the mean.
Source: Lopez *et al*. 2006.

wetlands in a specific inland and coastal region of the historical lake plain (Fig. 4).

Standard Deviation
Classes describe the distribution of percentage of forest or percentage of grassland adjacent to wetlands (among reporting units) relative to the mean value for the metric distribution. Class breaks are generated by successively described by standard deviations from the mean value for the metric. A two-color ramp (red to blue) emphasizes values (above to below) the mean value for a metric, and is a useful method for visualizing spatial variability of a metric.

Pressures
Although several causal relationships have been postulated for changes in "Land Cover Adjacent to Coastal Wetlands" for the Great Lakes basin (Lopez *et al*. 2006), it is undetermined as to the relative contribution of the various factors. However, some preliminary regional trends exist. For example, in the 1 km coastal region of southern Lake Superior there is a relatively high percent of forest adjacent to coastal wetlands, and in the 1 km coastal region of western Lake Michigan there is a relatively low percent of forest adjacent to coastal wetlands. Differences in percent forest between these two coastal zones generally track with respect to percent of agricultural land cover or urban land cover, as measured with similar techniques. These results are preliminary and observations are not conclusive. Similar phenomena are currently under investigation and proposed for additional regional and full-basin investigation.

Management Implications
Because critical forest and grassland habitat areas on the periphery of coastal wetlands may influence the presence and fitness of localized and migratory organisms in the Great Lakes, natural resource managers may use these data to determine the ranking of their areas of interest, such as areas where they are responsible for coastal wetland resources, among other areas in the Great Lakes. It is important for managers to understand that results for their areas of interest are reported among a distribution for the entire Great Lakes basin and that caution should be used when interpreting the results at finer scales.

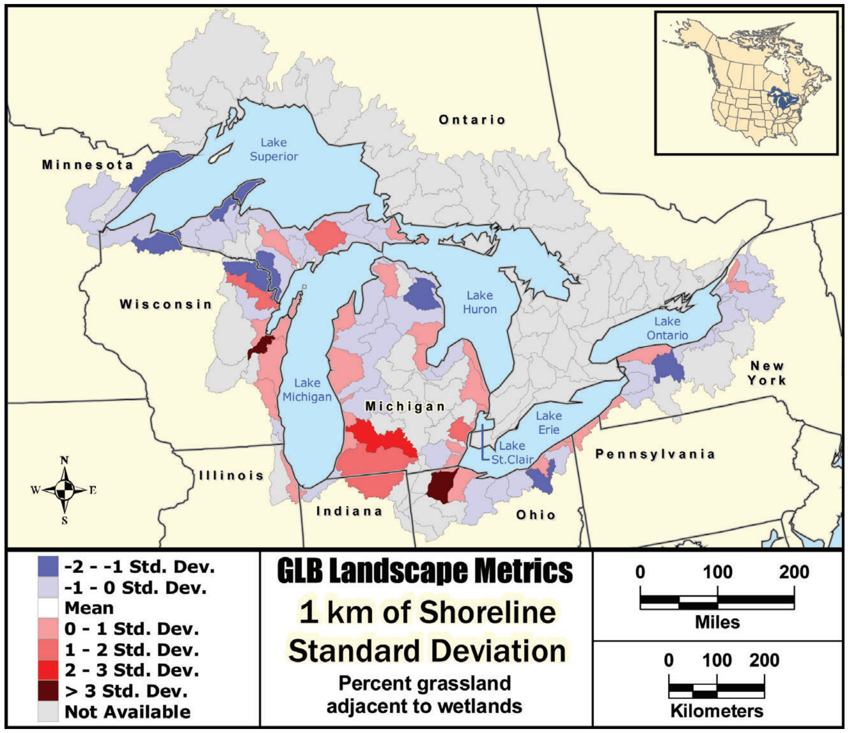

Figure 3. Percent grassland adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 1 km of shoreline; data are reported as standard deviations from the mean.
Source: Lopez *et al*. 2006.

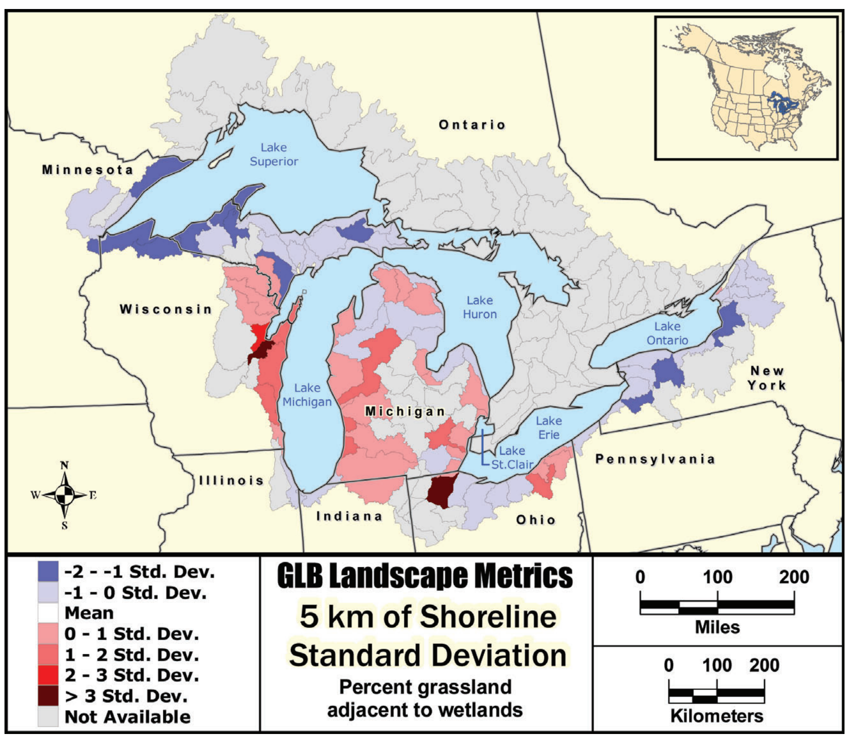

Figure 4. Percent grassland adjacent to wetlands, among 8-digit USGS Hydrologic Unit Codes (HUCs), measured within 5 km of shoreline; data are reported as standard deviations from the mean.
Source: Lopez *et al*. 2006.

Comments from the author(s)
To conduct such measures at a broad scale, the relationships between wetland-adjacent land cover and the functions of coastal wetlands need to be verified. This measure will need to be validated fully with thorough field sampling data and sufficient a priori knowledge of such endpoints and the mechanisms of impact. The development of indicators (e.g., a regression model using adjacent vegetation characteristics and wetland hydroperiod) is an important goal, and requires uniform measurement of field parameters across a vast geographic region to determine accurate information to calibrate such models.

Acknowledgments
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Last Updated
State of the Great Lakes 2007

Urban Density
Indicator #7000

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **There is insufficient data on urban centres across the basin. A major challenge remains generation of consistent binational, multi-temporal statistics.**

Purpose
- To assess the urban human population density in the Great Lakes basin
- To infer the degree of land use efficiency for urban communities in the Great Lakes ecosystem

Ecosystem Objective
Socio-economic viability and sustainable development are the generally acceptable goals for urban growth in the Great Lakes basin. Socio-economic viability indicates that development should be sufficiently profitable and social benefits are maintained over the long-term. Sustainable development requires that we plan our cities to grow in a way so that they will be environmentally sensitive, and not compromise the environment for future generations. Thus, by increasing the densities in urban areas while maintaining low densities in rural and fringe areas, the amount of land consumed by urban sprawl will be reduced.

State of the Ecosystem
Background
Urban density is defined as the number of people per square kilometer of land for urban use in a municipal or township boundary. Lower urban densities are indicative of urban sprawl; that is, low-density development beyond the edge of service and employment, which separates residential areas from commercial, educational and recreational areas thus requiring automobiles for transportation (TCRP 1998, TCRP 2003, Neill *et al*. 2003). Urban sprawl has many detrimental effects on the environment. The process consumes large quantities of land, multiplies the required horizontal infrastructure (roads and pipes) needs, and increases the use of personal vehicles while the feasibility of alternate transportation declines. When there is an increased dependency on personal vehicles, an increased demand for roads and highways follows, which in turn promotes 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 increases the average time spent traveling and reduces the sense of community derived from public interaction.

A number of factors need to be taken into account when assessing urban density. First, urban areas are complex and density alone encapsulates only place of residence demographics and not employment attributes. Second, while a primary focus has been on viewing high density as desirable (e.g. to combat the detrimental aspects of sprawl such as automobile dependence, land use pressures, etc), there are potential costs associated with this goal such as congestion, enhance urban heating, quality of life, etc.

This indicator offers information on the presence, location, and predominance of human-built land cover and infers the intensity of human activity in the urban area. It may provide information about how such land cover types affect the ecological characteristics and functions of ecosystems, as demonstrated by the use of remote-sensing data and field observations.

Status of Urban Density
Within the Great Lakes basin, there are 10 Census Metropolitan Areas (CMAs) in Ontario and 24 Metropolitan Statistical Areas (MSAs) in the United States. In Canada, a CMA is defined as an area consisting of one or more adjacent municipalities situated around a major urban core with a population of at least 100,000. In the United States, an MSA must have at least one urbanized area of 50,000 or more inhabitants and at least one urban cluster of at least a population of 10,000 but less than 50,000. The urban population growth in the Great Lakes basin shows consistent patterns in both the United States and Canada. The population in both countries has been increasing over the recent decades. According to the Statistics Canada reports, between 1996 and 2006, the population of the Great Lakes basin CMAs grew from 7,041,985 to 8,187,945, an increase of 1,145,960 or 16.27% in 10 years. The 2000 U.S. census reports that from 1990 to 2000 the population contained in the MSAs of the Great Lakes basin grew from 26,069,654 to 28,048,813, an increase of 1,979,159 or 7.6% in 10 years.

In the Great Lakes basin, while there has been an increase in population, there has also been an increase in the average population densities of the CMAs and MSAs. However, using the CMA or MSA as urban delineation has two major limitations. First, CMAs and MSAs contain substantial rural land areas and by themselves result in over-estimation of the land area occupied by a city or town. Second, these area delineations are based on a population density threshold and hence provide information on residential distribution and not necessarily on other urban land categories such as commercial or recreational land. If within the CMAs and MSAs the amount of land being developed is escalating at a greater rate than the population growth rate, the average amount of developed land per person is increasing. For example, "In the Greater Toronto Area (GTA) during the 1960s, the average amount of developed land per person was a modest 0.019 hectares (0.047 acres). By 2001 that amount tripled to 0.058 hectares per person (0.143 acres)" (Gilbert *et al*. 2001).

While density is a readily understandable measure, it is challenging to quantify because of the difficulty in estimating true urban extent in a consistent and unbiased way. The political geographic extents of MSAs and CMAs give approximate indications of relative city size. However, they tend to contain substantial areas of rural land use. Recently, satellite remote sensing data have been used to map land use of Canadian cities as part of a program to develop an integrated urban database, the Canadian Urban Land Use Survey (CUrLUS). In southern Ontario, a total of 11 cities have been mapped (using Landsat data acquired in the 1999 to 2002 timeframe) and their densities estimated using population statistics from the 2001 Canadian census (Fig. 1). Population density tends to correlate positively with the city size. Comparing the population densities of 11 cities (or CMAs) in southern Ontario, derived from remote sensing mapping and 2001 census (Zhang and Guindon 2005), the GTA has a higher population density (2848 people /km^2, 7376 people/mi^2) than other smaller cities.

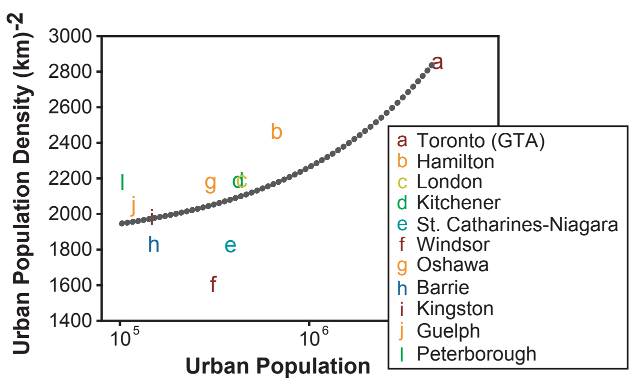

Figure 1. Population densities of cities with populations more than 100,000 in southern Ontario of the Great Lakes watershed for 2001.
Source: Y. Zhang and B. Guindon, private communication.

The growth characteristics of five large Canadian cities have also been studied for the period from 1986 to 2000. Preliminary analyses (Fig. 2) indicate the areal extents of these communities have grown at a faster rate than their populations and thus that sprawl continues to be a major problem.

A comparison of the 10 CMAs and MSAs with the highest densities to the 10 CMAs and MSAs with the lowest densities in the Great Lakes basin shows there is a large range between the higher densities and lower densities. Three of the 10 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.

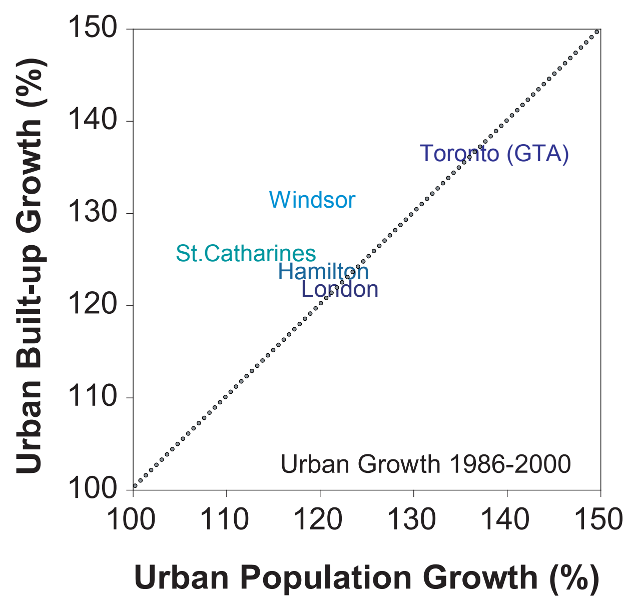

Figure 2. Growth characterization of 5 urban areas in the period of 1986-2000.
Source: Y. Zhang and B. Guindon, private communication.

Over the past two years progress has been made to further address the need for baseline urban information. A Great

Lakes urban database, the Great Lakes Urban Survey (GLUS) has been assembled that provides quantitative information on the state of urban form of the 22 MSAs/CMAs (Table 1) in the region with populations in excess of 200,000 (circa 2000 epoch). A fundamental information layer of GLUS is land cover/land use derived in part from Landsat satellite data. This information provides a precise estimate of urban land in each MSA/CMA, a perquisite for accurate density estimation. Additional layers include census tract level information on population, employment and work-related travel statistics. Figure 3 summarizes urban density estimates for these 22 centres.

CMA/MSA	Population	CMA/MSA	Population
Chicago-Gary IL/IN	9 157 540	Kalamazoo-Battle Creek, MI	452 851
Detroit/Ann Arbour-Flint, MI	5 456 428	Lansing-East Lansing, MI	447 728
Greater Toronto Area, ON	4 682 897	London, ON	432 451
Cleveland-Akron, OH	2 945 831	Kitchener-Waterloo, ON	414 284
Milwaukee-Racine, WI	1 689 572	Saginaw-Bay City, MI	403 070
Buffalo-Niagara Falls, NY	1 170 111	St. Catharines-Niagara Falls, ON	377 094
Rochester, NY	1 098 201	Windsor, ON	307 877
Grand Rapids-Muskegon-Holland, MI	1 088 514	Oshawa, ON	296 298
Syracuse, NY	732 117	Erie, PA	280 843
Hamilton, ON	662 401	South Bend, IN	265 559
Toledo, OH	618 203	Green Bay, WI	226 778

Table 1. Great Lakes urban areas with populations in excess of 200,000 (based on 2000 U.S. and 2001 Canadian census data).
Source: U.S. Census Bureau, 2000 and Statistics Canada, 2001.

There are number of points to note including (a) a distinct density differences between U.S. and Canadian urban areas and (b) an apparent trend, strong among Canadian CMAs and weaker among U.S. MSAs of increasing density with population. While it is important to monitor growth of large cities, it is imperative that surrounding regions need to be monitored to account for the extensive development of recreational areas (e.g. 'cottage country') as well smaller urban centres that have become attractive retirement communities.

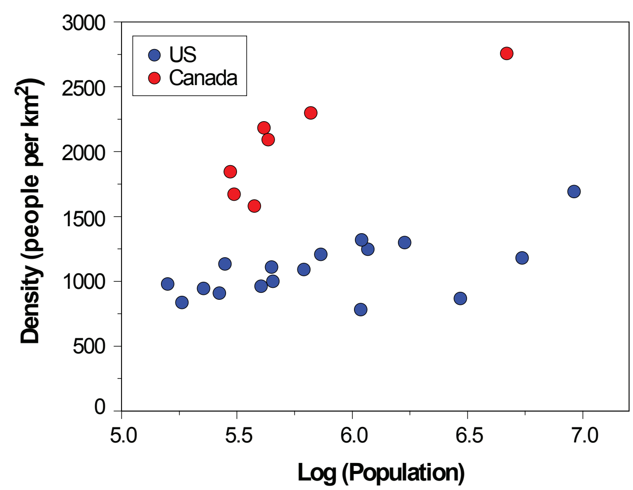

Figure 3. Urban density vs population for 22 MSAs and CMAs.
Source: B. Guindon and Y. Zhang, private communication.

Pressures

Under the pressure of rapid population growth in the Great Lakes region, mostly in the metropolitan cities, urban development has been undergoing unprecedented growth. For instance, the urban built-up area of the GTA has doubled since 1960s. Sprawl is increasingly becoming a problem in rural and urban fringe areas of the Great Lakes basin, placing a strain on infrastructure and consuming habitat in areas that tend to have healthier environments than those that remain in urban areas. This trend is expected to continue, which will exacerbate other problems, such as increased consumption of fossil fuels, longer commute times from residential to work areas, and fragmentation of habitat. For example, at current rates in Ontario, residential building projects will consume some 1,000 km^2 (386 mi^2) 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's effects 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 data are 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 transit, while respecting adjacent natural areas, will help alleviate the pressure from development.

For sustainable urban development, we should understand fully the potential negative impacts of urban high density development. High urban density indicates intensified human activity in the urban area, which could produce potential threats to the quality of the urban environment. Therefore, the urbanization strategies should be based on the concept of sustainable development with a balance of the costs and benefits.

Comments from the author(s)

A thorough field-sampling protocol, properly validated geographic information, and other remote-sensing-based data could lead to successful development of urban density as an indicator of ecosystem function and ecological vulnerability in the Great Lakes basin. This indicator could be applied to select sites, but would be most effective if used at a regional or basin-wide scale. Displaying U.S. and Canadian census population density on a GIS-produced map will allow increasing sprawl to be documented over time in the Great Lakes basin on a variety of scales. For example, the maps included with the 2003 Urban Density report show the entire Lake Superior basin and a closer view of the southwestern part of the basin.

To best quantify the indicator for the whole Great Lakes watershed, a watershed-wide consistent urban built-up database is needed.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments
Authors:
Bert Guindon, Natural Resources Canada, Ottawa, ON (2008)
Ying Zhang, Natural Resources Canada, Ottawa, ON (2008)
Ric Lopez, U.S. Environmental Protection Agency, Las Vegas, NV (2006)
Lindsay Silk, Environment Canada Intern, Downsview, ON (2004)

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Last Updated
State of the Great Lakes 2009

Land Cover/Land Conversion

Indicator #7002

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **Low-intensity development increased 33. 5%, road area increased 7. 5%, and forest decreased 2. 3% from 1992 to 2001. Agriculture lost 210,000 ha (520,000 acres) of land to development. Approximately 50% of forest losses were due to management and 50% to development.**

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Undetermined
Rationale: Lowest conversion rate of non-developed land to developed and highest conversion rate of non-forest to forest. Of the 4. 2 million ha (10. 4 million acre) watershed area in the U. S. basin, 1,676 ha (4141 acres) of wetland, 2,641 ha (15,422 acres) of agricultural land, and 14,300 ha (35,336 acres) of forest land were developed between 1992 and 2001.

Lake Michigan
Status: Mixed
Trend: Undetermined
Rationale: Intermediate to high rate of land development conversions. Of the 1. 2 million ha (3. 0 million acre) watershed, 9,724 ha (24,028 acres) of wetland, 78,537 ha (193,624 acres) of agricultural land, and 57,529 ha (142,157 acres) of forest land were developed between 1992 and 2001.

Lake Huron
Status: Fair
Trend: Undetermined
Rationale: Second lowest rate of conversion of land to developed. Of the 4. 1 million ha (10. 1 million acre) watershed area in the U. S. basin, 4,314 ha (10,660 acres) of wetland, 17,881 ha (44,185 acres) of agricultural land, and 17,730 ha (43,812 acres) of forest land were developed between 1992 and 2001.

Lake Erie
Status: Poor
Trend: Undetermined
Rationale: Highest conversion rate of non-developed to developed area. Of the 5. 0 million ha (12. 4 million acre) watershed area in the U. S. basin, 3,352 ha (8,283 acres) of wetland, 52,502 ha (129,735 acres) of agricultural land, and 27,869 ha (68,866 acres) of forest land were developed between 1992 and 2001.

Lake Ontario
Status: Mixed
Trend: Undetermined
Rationale: Intermediate to high conversion rate of non-developed to developed land use coupled with the lowest rates of wetland development. Of the 3. 4 million ha (8. 4 million acre) watershed area in the U. S. basin, 458 ha (1,132 acres) of wetland, 24,883 ha (61,487 acres) of agricultural land, and 20,670 ha (51,076 acres) of forest land were developed between 1992 and 2001.

Purpose

- To document the proportion of land in the Great Lakes basin under major land use classes
- To assess the changes in land use over time
- 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 (United States and Canada 1987).

State of the Ecosystem

Binational land use data from the early 1990s were developed by Bert Guindon (Natural Resources Canada). Imagery data from the North American Landscape Characterization and the Canada Centre for Remote Sensing archive were combined and processed into land cover using Composite Land Processing System software. This data set divides the basin into four major land use classes: water, forest, urban, and agriculture and grasses.

Later, finer-resolution satellite imagery allowed an 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.

In the U. S. portion of the basin, the Natural Resources Research Institute (NRRI) of the University of Minnesota – Duluth has developed a 25-category classification scheme (Table 1) based on 1992 National Land Cover Data (NLCD) from the U. S. Geological Survey supplemented by 1992 WISCLAND, 1992 GAP, 1996 C-CAP and raw Landsat TM data to increase resolution in wetland classes (Wolter *et al.* 2006). The 1992 Topologically Integrated Geographic

(1)	Low Intensity Residential	1	Developed
(1)	High Intensity Residential	2	Agriculture
(1)	Commercial/Industrial	3	Early Successional Vegetation
(1)	Roads (Tiger 1992)	4	Forest
(3)	Bare Rock/Sand/Clay	5	Wetland
(1)	Quarries/Strip Mines/Gravel Pits	6	Miscellaneous Vegetation
(6)	Urban/Recreational Grasses		
(2)	Pasture/Hay		
(2)	Row Crops		
(2)	Small Grains		
(3,6)	Grasslands/Herbaceous		
(2,6)	Orchards/Vineyards/Other		
(4)	Deciduous Forest		
(4)	Evergreen Forest		
(4)	Mixed Forest		
(3,6)	Transitional		
(3,6)	Shrubland		
(5)	Open Water		
(5)	Unconsolidated Shore		
(5)	Emergent Herbaceous Wetlands		
(5)	Lowland Grasses		
(5)	Lowland Scrub/Shrub		
(5)	Lowland Conifers		
(5)	Lowland Mixed Forest		
(5)	Lowland Hardwoods		

Table 1. Classification scheme used to analyze LU/LC change in the U. S. portion of the Great Lakes basin. Original 25 classes are listed in the left column, while aggregated LU/LC categories are listed in the right column. Numbers in parentheses indicate aggregated class membership. Miscellaneous vegetation class was generated (code 6) to represent land that was vegetated, but not mature forest or annual row crop.
Source: Wolter *et al.* 2006.

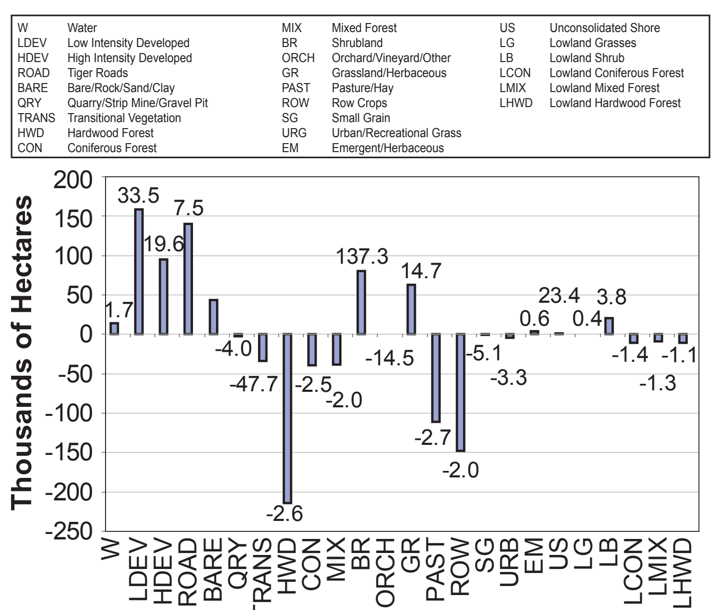

Figure 1. LU/LC type changes for the U. S. Great Lakes basin by area and percent change since 1992 (numbers above and below bars).
Source: Wolter *et al.* 2006.

Encoding and Reference (TIGER) data were also used to add roads on to the map. Within the U. S. basin, the NRRI found the following:

Between two nominal time periods (1992 and 2001), the U. S. portion of the Great Lakes watershed has undergone substantial change in many key land use/land cover (LU/LC) categories (Fig. 1). Of the total change that occurred (798,755 ha, 2. 5 % of watershed area), salient transition categories included a 33. 5 % increase in area of low-intensity development, a 7. 5% increase in road area, and a decrease of forest area by over 2. 3 %, the largest LU/LC category and area of change within the watershed. More than half of the forest losses involved transitions into early successional vegetation (ESV), and hence, will likely remain in forest production of some sort. However, nearly as much forest area was, for all practical purposes, permanently converted to developed land. Likewise, agriculture lost over 50,000 more hectares (125,000 acres) of land to development than forestland, much of which involved transitions into urban/suburban sprawl (Fig. 2). Approximately 210,068 ha (81 %) of agricultural lands were converted to development, and 16. 3 % of that occurred within 10 km of the Great Lakes shoreline.

LU/LC transitions between 1992 and 2001 within near-shore zones of the Great Lakes (0-1, 1-5, 5-10 km) largely paralleled those of the overall watershed. While the same transition categories dominated, their proportions varied by buffered distance from the lakes. Within the 0-1 km zone from the Great Lakes shoreline, conversions of forest to both ESV (9,087 ha, 5.0 % of total category change (TCC)) and developed land (8,657 ha, 5.6 % of TCC) were the largest transitions, followed by conversion of 3,935 ha (1.9 % of TCC) of agricultural land to developed. For the 1-5 km zone inland from the shore, forest to developed conversion was the largest of the three transitions (17,049 ha, 11.0 % of TCC), followed by agricultural to developed (14,279 ha, 6.8 % of TCC) and forest to ESV (13,116 ha, 7.3 % of TCC). Within the 5-10 km zone from shoreline, transition category dominance was most similar to the trend for the whole watershed, with 16,113 ha (7.7 % of TCC) of agriculture converted to developed, 14,516 ha (8.0 % of TCC) of forest converted to ESV, and 14,390 ha (9.3 % of TCC) of forestland being developed by 2001. When all buffers from shoreline out to 10 km are combined, the forest to developed transition category was the largest (40,099 ha, 25.9 % of TCC), followed by forest to ESV (36,726 ha, 20.3 % of TCC), and agricultural to developed (34,328 ha, 16.3 % of TCC).

Contrary to previous decadal estimates showing an increasing forest area trend from the early 1980s to the early 1990s, due to agricultural abandonment and transitions of forest land away from active management, there was an overall decrease (~2.3 %) in forest area between 1992 and 2001. Explanation of this trend is largely unclear. However, increased forest harvesting practices in parts of the region coupled with forest clearing for new developments may be overshadowing gains from the agricultural sources observed in previous decades.

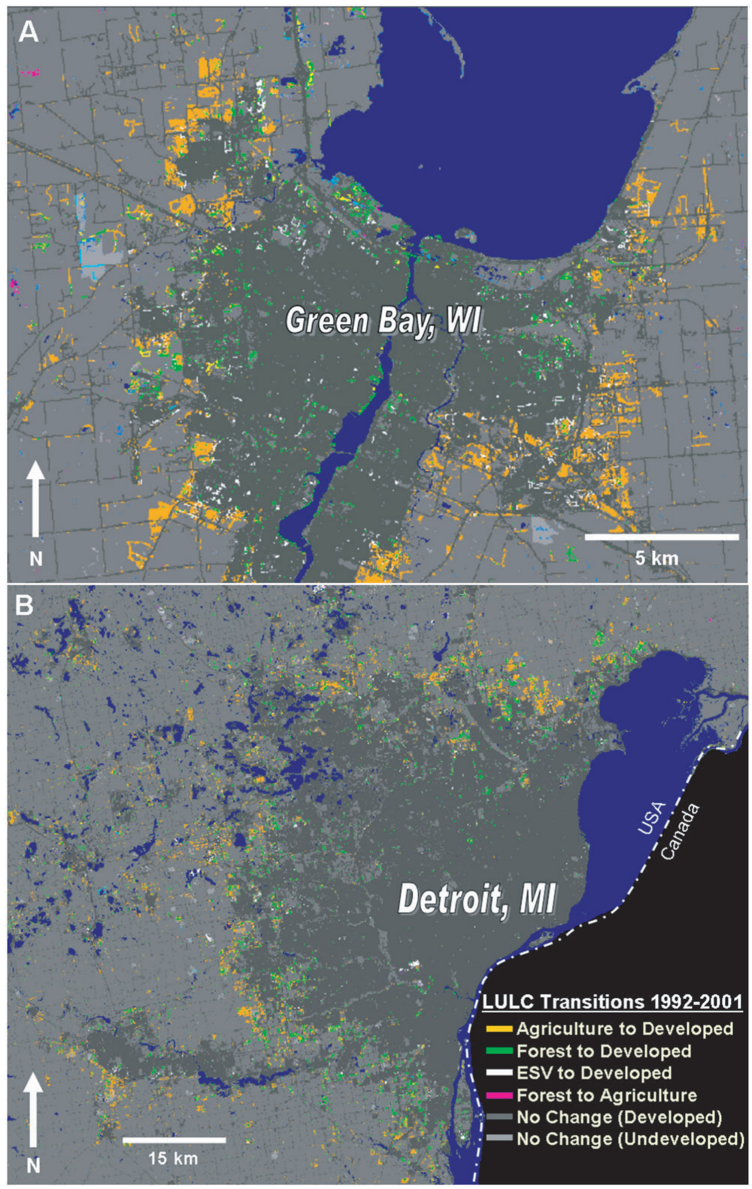

Figure 2. LU/LC change in the lower Green Bay basin of Lake Michigan (A) and the area surrounding Detroit, MI (B).
Source: Wolter *et al.* 2006.

	Erie	Huron	Michigan	Ontario	Superior	St. Clair	Erie/St. Clair
Total watershed area	4994413	4114697	11702442	3428229	4226924	564825	5559238
Non-dev. to developed	87077	42857	155936	46507	20351	16112	103189
% of watershed	1. 74	1. 04	1. 33	1. 36	0. 48	2. 85	1. 86

Table 2. Total area (ha) and proportion of watershed converted from non-developed to developed LU/LC from 1992 to 2001 for each of the Great Lakes and Lake St. Clair.
Source: Wolter *et al.* 2006.

When analyzed on a lake-by-lake basis (Fig. 3, Table 2), Lake Michigan's watershed naturally has shown the greatest area of change from 1992 to 2001 (286,587 ha, ~2.5 %), because its watershed is entirely within the U. S. , and hence, the largest analyzed. Lake Michigan's watershed leads in all LU/LC transition categories but two: 1) miscellaneous vegetation to flooded and 2) ESV to forest (Fig. 3). When normalized by area, however, Lake Michigan's proportion of LU/LC change is intermediate when compared to the other Great Lakes watersheds on the U. S. side of the border. Although Lake St. Clair is not a Great Lake, and the U. S. part of its watershed is largely metropolitan (see Fig. 2), Lake St. Clair's watershed shows the highest rates of change into development from wetland, ESV, agriculture, and forest sources (Fig. 4).

Of the Great Lakes, Lake Erie's watershed shows the greatest proportion of land conversion to development (87,077 ha, 1.74 %), while Lake Superior's watershed had the lowest proportion (20,351 ha, 0.48 %, Table 2). For example, Lake Erie's watershed had the highest proportion of agricultural land conversion to development. However, Lake Ontario's watershed showed the greatest proportion of forest conversion to development (Fig. 4). Lake Superior's watershed reflects a high proportion of lands under forest management in that it has both the highest proportion of forest conversion to ESV and vice-versa. Lastly, Lake Huron's watershed had the highest proportion of wetlands being converted to development, followed closely by watersheds for Lake Michigan and Lake Erie (Fig. 4).

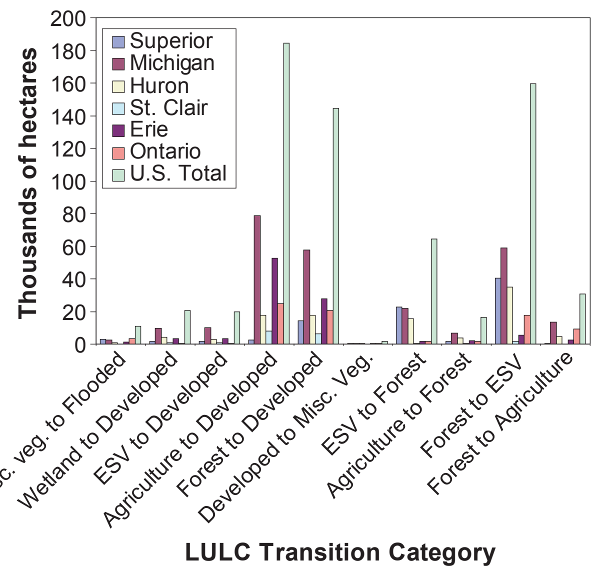

Figure 3. Lake-by-lake LU/LC transitions for the U. S. portion of the Great Lakes basin.
Source: Wolter *et al.* 2006.

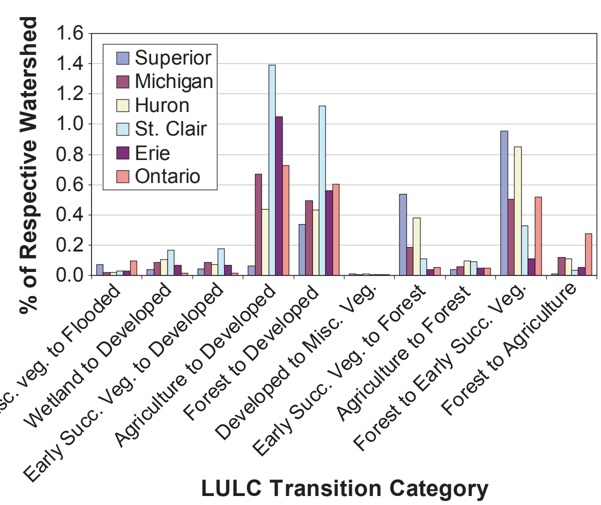

Figure 4. Lake-by-lake LU/LC transitions for the U. S. portion of the Great Lakes basin as a percent of respective watershed area.
Source: Wolter *et al.* 2006.

Management Implications

As the volume of data on land use and land conversion grows, stakeholder discussions will assist in identifying the associated pressures and management implications.

Comments from the author(s)

Land classification data must be standardized. The resolution should be fine enough to be useful at lake watershed and sub-watershed levels. LU/LC classification updates need to be completed in a timely manner to facilitate effective remedial action if necessary.

Acknowledgments

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Sources

Data courtesy of: Bert Guindon (Natural Resources Canada)
Lawrence Watkins (Ontario Ministry of Natural Resources)
Peter Wolter (Natural Resources Research Institute at the University of Minnesota – Duluth).

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Last updated

State of the Great Lakes 2007

Brownfields Redevelopment

Indicator #7006

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Rationale: **Data from multiple sources are not consistent. Inventories of existing brownfields are not available in Ontario, so it is difficult to determine a trend for the redevelopment of brownfields. Since more sites are being redeveloped and/or are being planned, there is some trend of an improvement in the Great Lakes basin, but it is not based on a quantitative assessment.**

Lake-by-Lake Assessment

Individual lake basin assessments were not prepared for this report.

Purpose

- To assess the area of redeveloped brownfields
- 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:

- Reduction or elimination of environmental risks from contamination associated with these properties
- Reductions in pressure for open space conversion as previously developed properties are reused

State of the Ecosystem

Brownfields are abandoned, idled, or under-used industrial and commercial facilities where expansion, redevelopment or reuse is complicated by real or perceived environmental contamination. In 1999, 21,178 brownfields sites were identified in the United States, which was equivalent to approximately 33,010 hectares (81,568 acres) of land (The United States Conference of Mayors 2000). Although similar research does not exist for Canada, and no inventory exists for either contaminated or brownfields sites in Ontario, it is estimated that approximately 50,000 to 100,000 brownfields sites may exist in Canada (Globe 2006).

All eight Great Lakes states, Ontario and Quebec have programs to promote remediation or clean-up and redevelopment of brownfields sites. Several of the brownfields clean-up programs have been in place since the mid- to late 1980s, but establishment of more comprehensive brownfields programs that focus on remediation and redevelopment has occurred during the 1990s. Today, each of the Great Lakes states has a voluntary clean-up or environmental response program and there are over 5,000 municipalities with some type of brownfields program in the United States (Globe 2006). These clean-up programs offer a range of risk-based, site-specific background and health clean-up standards that are applied based on the specifics of the contaminated property and its intended reuse.

In Quebec, the *Revi-Sols* program was established in 1998 and is aimed at assessing and cleaning urban contaminated sites for the purpose of reuse. Through this program, it was possible to collect some data on the number of contaminated sites in Quebec, as it was compulsory for the land owner to report this information to complete the application for financing. Based on this program, more than 7,000 sites are included in this inventory.

To encourage redevelopment, Ontario's environmental legislation provides general protection from environmental orders for historic contamination to municipalities, creditors and others. Ontario Regulation 153/04, which came into effect on October 1, 2004, details the requirements that property owners must meet in order to file a record of site condition. Two technical documents are referenced by this regulation, one providing applicable site condition standards, the other providing laboratory analytical protocols for the analysis of soil, sediment and ground water. A Brownfields Environmental Site Registry offers property owners the opportunity to complete an online record of site condition, and this information is then publicly accessible. This registry is currently voluntary. As of October 2005, property owners are required to file a record of site condition before a property's use is changed from an industrial or commercial use to a more sensitive use, such as residential. A record of site condition ensures that a property meets regulated site-assessment and clean-up standards that are appropriate for the new use (Ontario Ministry of the Environment 2006).

The 2003 enactment of the New York State Brownfield Law has resulted in increased interest by private developers and municipalities in the redevelopment of contaminated properties.

Efforts to track brownfields redevelopment are uneven among Great Lakes states and provinces. Not all jurisdictions track brownfields activities, and methods vary where tracking does take place. States, provinces and municipalities track the amount of funding assistance provided as well as the number of sites that have been redeveloped. They also track the number of applications that have been received for brownfields redevelopment funding. These are indicators of the level of brownfields redevelopment activity in general, but they do not necessarily reflect land renewal efforts (i.e., area of land redeveloped), the desired measure for this indicator. Compiling state and provincial data to report a brownfields figure that represents the collective eight states and two provinces is challenging. Several issues are prominent. First, state and provincial clean-up data reflect different types of clean-ups, not all of which are brownfields (e.g., some include leaking underground storage tanks and others do not). Second, some jurisdictions have more than one program, and not necessarily all relevant programs engage in such tracking. Third, program figures do not include clean-ups that have not been part of a state or provincial clean-up program (e.g., local or private clean-ups). Several states and provinces do track area of brownfields remediated, although no Great Lakes state or province tracks area of brownfields redeveloped.

Information on area of brownfields remediated from Illinois, Minnesota, New York, Ohio, Pennsylvania, Quebec and Ontario indicate that, as of August, 2007, a total of 18,309 hectares (45,244 acres) had been remediated (Table 1). Available data from eight Great Lakes states, Quebec and Ontario indicate that approximately 32,250 brownfields sites have participated in brownfields clean-up programs since the mid-1990s, although the degree of remediation varies considerably. In Ontario, brownfields redevelopment was planned for 108 hectares (267 acres) of land between 2006 and 2008 for the municipalities that participated in this assessment.

State/ Province	Acres remediated	Hectares remediated	Time frame	Sites remediated	Time frame
WI	4,943	2,000	2004-2007	19,092	1994-2007
PA	25,607	10,363	1995-2007	2,307	1995-2007
OH	4,163	1,685	1994-2007	218	1994-2007
MI	not tracked			8,300†	1995-2007
IN*	757	306	1998-2007	164	1998-2007
MN	7,443	3,012	1989-2007	523	1989-2007
IL	13,678	5,535	1990-2007	2,519	1990-2007
NY**	373	151	1996-2008	226	1994-2008
ON	235	95	2002-2005	13	2002-2005
QC	741	300	1998-2002	309	1998-2005
Total	57,940	23,447		33,671	

Table 1. Summary of acres remediated and number of sites remediated in the Great Lakes basin states, and the provinces of Ontario and Quebec, 1990 – 2007.
†Reflects number of sites that have been subject to a baseline environmental assessment, but not necessarily remediation.
*Total reflects number of sites that have been remediated and/or have received closure with the use of Environmental Restrictive Covenants. Acreage remediated not reported for every site prior to 2001.
**Totals incorporate data from the NY Voluntary Cleanup Program (1994-2008, no acreage information), Brownfield Cleanup Program (2003-2008), and Environmental Restoration Program (1996-2008).
Source: Various state, municipal and provincial brownfields coordinators and city planners.

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 are inconsistent and inadequate data on area of brownfields remediated and/or redeveloped, available data indicate that both brownfields clean-up and redevelopment efforts have risen dramatically in the mid-1990s and steadily since 2000. The increase is due to risk-based clean-up standards and the widespread use of state liability relief mechanisms that allow private parties to redevelop, buy or sell properties without being liable for contamination they did not cause. Canadian law does not provide liability exemptions for new owners such as those in the U.S. Small Business Liability Relief and Brownfields Revitalization Act (Globe 2006). Environmental liability is a major barrier to successful brownfields redevelopment in Canada. Current owners do not want to sell brownfields sites for fear of liability issues in the future, purchasers of land do not want to buy sites without some level of protection and municipalities assume liability when they become site owners (City of Hamilton Planning and Development Department 2007). The Municipal Statute Law Amendment Act, 2006 which received Royal Assent on December 20, 2006 removes provincial Crown liens where a municipality chooses to assume ownership of a property that has failed a tax sale. Municipalities are now also able to advertise eligible brownfields properties as "free and clear" of all provincial crown liens upon sale. This change in legislation should reduce some of the issues related to civil and regulatory liabilities.

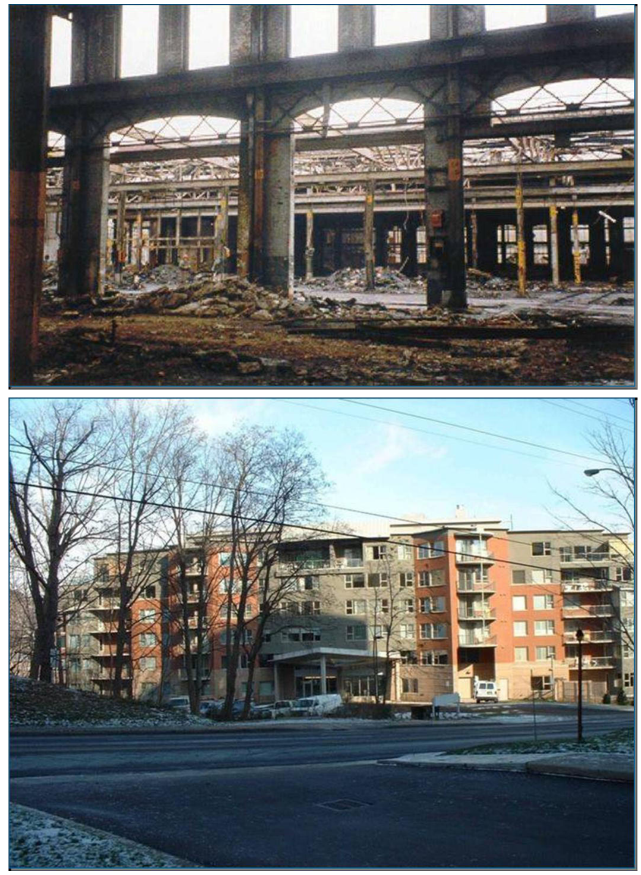

Figure 1. Brownfield site (top) and redevelopment of the same brownfield site (below), Spencer Creek, Hamilton, Ontario.
Source: City of Hamilton.

In 2005, the Government of Canada allocated $150 million for brownfields remediation. Other initiatives include the Sustainable Technologies Canada Funding, and the Federal Contaminated Sites Action Plan. Also, more financial tools for brownfields redevelopment are available though a Community Improvement Plan (CIP), which allows municipalities to encourage brownfields redevelopment by offering financial incentives. Other grants and loans can be provided to supplement the CIP including an exemption or a reduction in the cost of fees associated with permits, parkland dedications and zoning amendments. Tax incentives can also be provided by municipalities to encourage the cleanup of contaminated sites (Ontario Ministry of Municipal Affairs and Housing, 2006).

Data also indicate that the majority of clean-ups in the Great Lakes states and provinces are occurring in older urbanized areas, many of which are located on the shoreline of the Great Lakes and in the basin. Based on the available information, the state of brownfields redevelopment is mixed and improving.

Pressures

Laws and policies that encourage new development to occur on undeveloped land instead of on urban brownfields are significant and on-going pressures against brownfield development can be expected to continue. Programs to monitor, verify and enforce effectiveness of exposure controls are in their infancy, and the potential for human exposure to contaminants may inhibit the redevelopment of brownfields. Several Great Lakes states allow brownfields redevelopment to proceed without cleaning up contaminated groundwater as long as no one is going to use or come into contact with that water. However, where migrating groundwater plumes ultimately interface with surface waters, some surface water quality may continue to be at risk from brownfields contamination even where brownfields have been remediated.

Management Implications

Programs to monitor and enforce exposure controls need to be fully developed and implemented. More research is needed to determine the relationship between groundwater supplies and Great Lakes surface waters and their tributaries. Because brownfields redevelopment results in both reduction or elimination of environmental risks from past contamination and reduction in pressure for open space land conversion, data should be collected that will enable an evaluation of each of these activities. For every hectare (2.5 acres) developed in a brownfields project, it can save an estimated minimum of 4.5 hectares (11 acres) of land from being developed in an outlying area (National Roundtable on the Environment and the Economy 2003).

Ontario is expected to add 3.7 million more people to its population in the next 25 years with most of the growth occurring in the Greater Golden Horseshoe (western end of Lake Ontario) (Ontario Ministry of Public Infrastructure Renewal 2006). Brownfields redevelopment needs to be a part of the planning and development reform in order to address the issue of urban sprawl.

Funding and liability issues are obstacles for brownfields redevelopment and can hinder progress.

Comments from the author(s)
Great Lakes states and provinces have begun to track brownfields remediation and or redevelopment, but the data are generally inconsistent or not available in ways that are helpful to assess progress toward meeting the terms of the Great Lakes Water Quality Agreement. Though some jurisdictions have begun to implement web-based searchable applications for users to query the status of brownfields sites, the data gathered are not necessary consistent, which presents challenges for assessing progress in the entire basin. States and provinces should develop common tracking methods and work with local jurisdictions incorporating local data to online databases that can be searched by: 1) area remediated; 2) mass of contamination removed or treated (i.e., not requiring an exposure control); 3) type of treatment; 4) geographic location; 5) level of urbanization; and 6) type of reuse (i.e., commercial, residential, open, none, etc.). A recent development in the province of Ontario is the designation of a Provincial Brownfields Coordinator who will coordinate provincial brownfields activities and provide a single point of access on brownfields in Ontario.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	x					
2. Data are traceable to original sources	x					
3. The source of the data is a known, reliable and respected generator of data	x					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			x			
5. Data obtained from sources within the U.S. are comparable to those from Canada	x					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		x				
Clarifying Notes:						

Acknowledgments
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City of Toronto, Glenn Walker, Economic Development Officer
City of Toronto Economic Development Corporation (TEDCO)
Province of Quebec, Michel Beaulieu

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Last Updated
State of the Great Lakes 2009

Sustainable Agriculture Practices

Indicator #7028

Overall Assessment

Status: **Not Assessed**
Trend: **Not Assessed (Undetermined)**

Lake-by-Lake Assessment

Separate lake assessments were not included in the last update of this report.

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, Food and Rural Affairs (OMAFRA) 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.

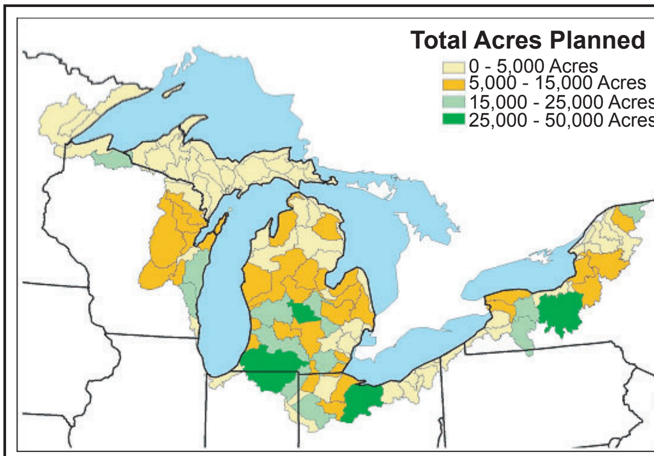

Figure 1. Acres of cropland in U.S portion of the basin covered under a conservation plan, 2003.
Source: Natural Resource Conservation Service, U.S. Department of Agriculture.

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), OMAFRA, 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 provided 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. 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.

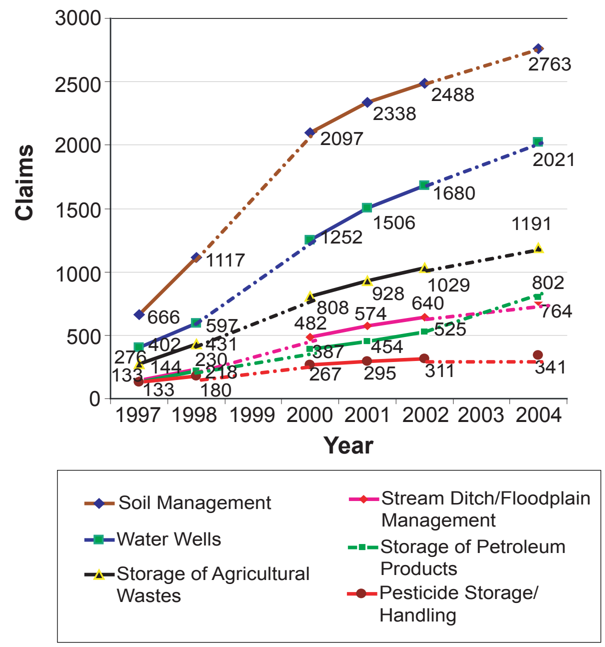

Figure 2. EFP: Cumulative Number of Incentive Claims by Worksheet (Issues).
Six of 23 worksheets/issues are represented here – these six worksheets represent 70% of all EFP incentive claims. Three worksheets (Soil, Water and Storage of Agricultural Wastes) represent significant environmental actions taken by farmers.
Source: Ontario Soil and Crop Improvement Association.

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 (odors) 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 multibillion 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, OMAFRA 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 (U.S. EPA) 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 U.S. EPA/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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization						
2. Data are traceable to original sources						
3. The source of the data is a known, reliable and respected generator of data						
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin						
5. Data obtained from sources within the U.S. are comparable to those from Canada						
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report						
Clarifying Notes:						

Acknowledgments
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Last Updated
State of the Great Lakes 2005

Economic Prosperity

Indicator #7043

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Note: Data are not system-wide.

Lake-by-Lake Assessment

Lake Superior
Status: Mixed
Trend: Undetermined

Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario were categorized with a not assessed status and an undetermined trend indicating that assessment were not made for these lakes.

Purpose

- To assess the unemployment rates within the Great Lakes basin
- 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 points above the U.S. average, and above the averages for their respective states, except occasionally Michigan (Fig. 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% in 1985. Unemployment rates in individual counties ranged considerably, from 8.6% to 26.8% in 1985.

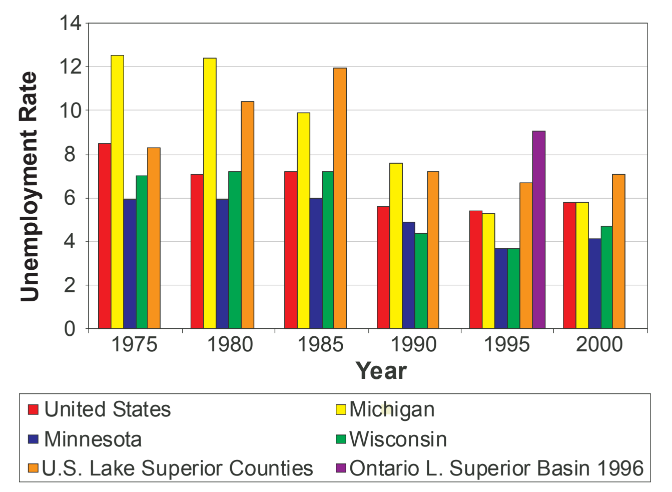

Figure 1. Unemployment rate in the U.S. (national), Michigan, Wisconsin, and the U.S. portion and Ontario portion of the Lake Superior basin, 1975-2000.
Source: U.S. Census Bureau and Statistics Canada.

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% 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.

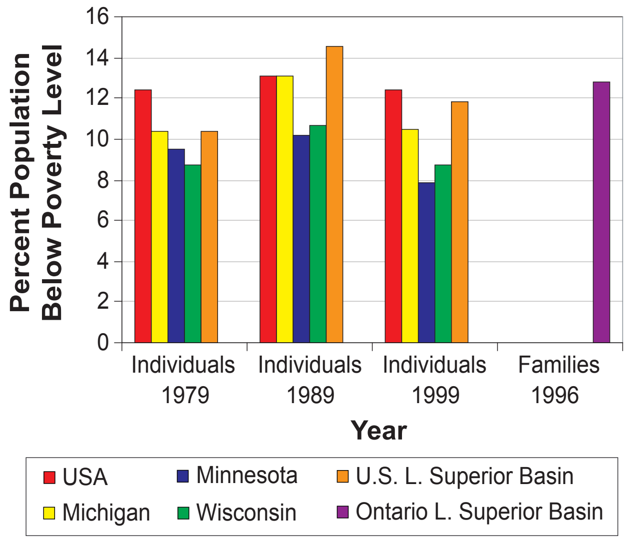

Figure 2. Individuals below poverty level in the U.S. (national), Michigan, Wisconsin, and the U.S. Great Lakes basin counties, 1979-1999, and families below poverty level in Ontario Great Lakes basin subdivisions, 1996.
Source: U.S. Census Bureau and Statistics Canada.

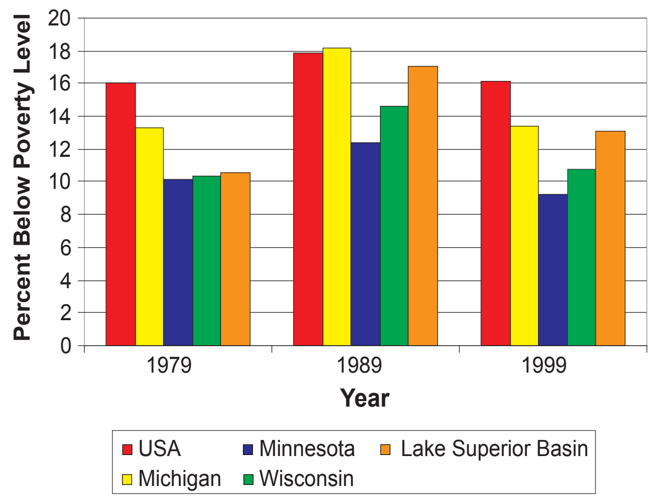

Figure 3. Children under age 18 below the poverty level, 1979-1999, United States (national), Michigan, Minnesota, Wisconsin and U.S. portion of the Lake Superior basin.
Source: U.S. Census Bureau.

Comments from the author(s)
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 United States 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 rate in U.S. Lake Superior basin (and the 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.

Acknowledgments
Authors:
Kristine Bradof, Groundwater Education in Michigan (GEM) Center for Science and Environmental Outreach, Michigan Technological University, MI; and
James G. Cantrill, Communication and Performance Studies, Northern Michigan University, MI.

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Last Updated
State of the Great Lakes 2003
[Editor's Note: Links to sources were updated for this publication when possible.]

Ground Surface Hardening

Indicator #7054

Overall Assessment

Status: **Fair**
Trend: **Undetermined**
Rationale: **Impervious surfaces cover 8.5% of the Great Lakes basin watersheds within U.S. borders and 1.3% within Canadian borders.**

Lake-by-Lake Assessment

Note: The status for the overall assessment and for each watershed individually was based on the following categorization of imperviousness: 0-5% = Good, >5%, but < 10% = Fair, >10% Poor.

Lake Superior
Status: United States - Good, Canada - Good
Trend: Undetermined
Rationale: Impervious surfaces cover 2.9% (1,282 sq. km.) of the watershed located in the United States and 0.01% (12 sq. km.) of the Canadian portion of the watershed.

Lake Michigan
Status: United States - Fair
Trend: Undetermined
Rationale: Impervious surfaces cover 8.14% (9,871 sq. km.) of the watershed, all of which is located within the United States.

Lake Huron
Status: United States - Fair, Canada - Good
Trend: Undetermined
Rationale: Impervious surfaces cover 7.37% (3,197 sq. km.) of the watershed located in the United States and 0.65% (606 sq. km.) of the Canadian portion of the watershed.

Lake Erie
Status: United States - Poor, Canada - Good
Trend: Undetermined
Rationale: Impervious surfaces cover 15.6% (9,006 sq. km.) of the watershed located in the United States and 2.25% (539 sq. km.) of the Canadian portion of the watershed.

Lake Ontario
Status: United States - Fair, Canada - Fair
Trend: Undetermined
Rationale: Impervious surfaces cover 6.5% (2,370 sq. km.) of the watershed located in the United States and 5.79% (1,734 sq. km.) of the Canadian portion of the watershed.

Purpose

- To indicate the degree to which impervious surfaces affect natural water drainage and cause rapid runoff and erosion, which are the main sources of non-point pollution.
- To measure the impact of land development on aquatic systems.

Ecosystem Objectives

A goal for the ecosystem is sustainable development. This would entail minimizing the quantities of impervious surfaces by using alternatives for replacement and future development.

State of the Ecosystem

Ground surface hardening, or imperviousness, is the sum of the area of roads, parking lots, sidewalks, roof tops, and other impermeable surfaces where water cannot be absorbed directly into the ground. These surfaces are mostly found in urban landscapes, and can serve as useful indicators with which to measure the impact of land development on aquatic ecosystems (Center for Watershed Protection 1994). With increasing population sizes, it is expected that ground surface hardening will increase as well.

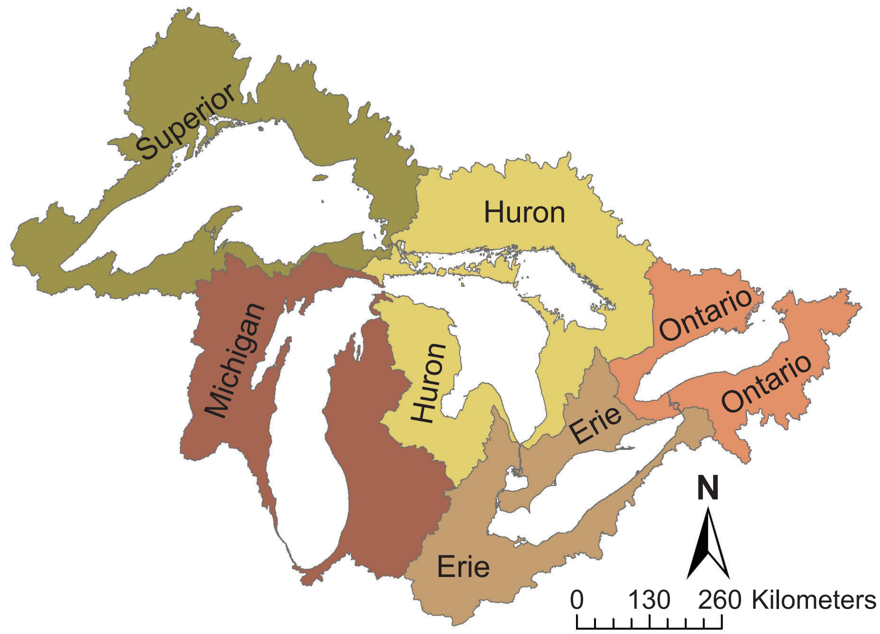

Figure 1. Map showing the 5 different Great Lakes watersheds located within both the U.S. and Canadian portions of the Great Lakes basin.
Source: Purdue University, Human-Environment Modeling and Analysis Laboratory and Great Lakes Information Network.

In the United States, a National Land Cover Database (NLCD) is created from satellite imagery which includes the percentage of impervious surfaces, and their associated impermeability rates, at a 30 m (98 ft) resolution. The most recent available NLCD dataset is for the year 2001; however, the 2006 dataset is currently under development. This 2001 dataset, along with U.S. Census county population data, was used to calculate three key metrics (the total sq. km. of impervious surfaces, the percentage of the watershed consisting of impervious surfaces, and the sq. km. of impervious surfaces per capita) for each Great Lake watershed (Fig. 1). Unlike the United States, there aren't any existing Canadian impervious surface datasets available. Thus, it became necessary to use the "settled and developed land" land use classification, from the Ontario land cover data (1:250,000 scale) produced by the Ontario Ministry of Natural Resources (OMNR), as a proxy for impervious surfaces within the Canadian region of the Great Lakes basin. Additionally, the available Canadian census data was too coarse to accurately determine the sq. km. of impervious surface per capita for the Canadian portion of the Great Lakes basin. However, the amount of impervious surfaces (based on the amount of "settled and developed land") was determined, as well as, the percentage of the Canadian portion of the watershed this area covers.

For the United States, the percent impermeability ranged from 1-100%, thus it became necessary to categorize in an effort to make the findings useful to a large number of individuals. The four categories are as follows: <20%, 20-49%, 50-79%, and 80-100%, which correspond to the NLCD land use classifications of developed open space, low intensity development, medium intensity development, and high intensity development, respectively.

As seen in Figure 2, the amount of impervious surfaces of different impermeabilities varies from watershed to watershed. It was also evident that the majority of the impervious surfaces consisted of matrices of roads and buildings leading to and located in large cities (Fig. 3). The Canadian data had a slightly different structure and could not be categorized based on different levels of impermeability. Figure 4 shows Toronto, Canada, which is represented in the data with the amount of impervious surfaces equal to the amount of "settled and developed land."

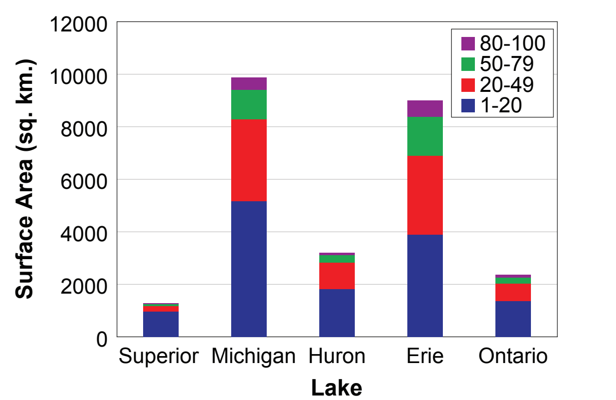

Figure 2. Lake-by-Lake amounts of impervious surface area (sq. km.) categorized by percent for their respective watershed areas in the USA.
Source: Purdue University, Human-Environment Modeling and Analysis Laboratory and Multi-resolution Land Characteristics Consortium.

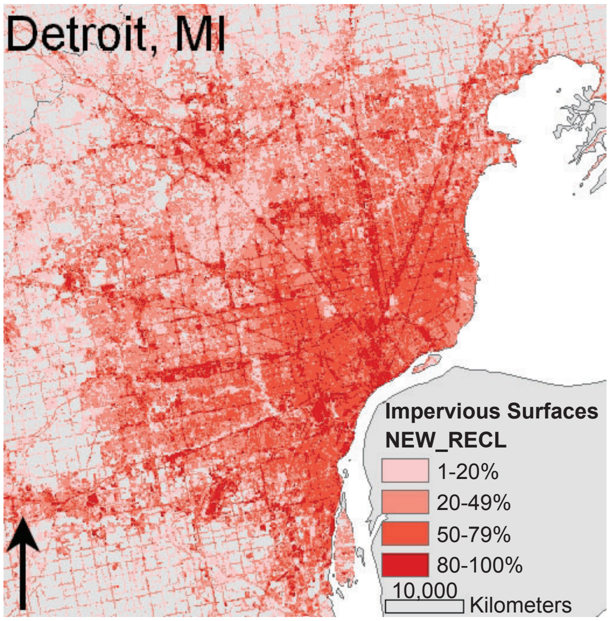

Figure 3. Detroit Michigan, United States showing percent impervious in NLCD categories.
Source: Purdue University, Human-Environment Modeling and Analysis Laboratory and Multi-resolution Land Characteristics Consortium.

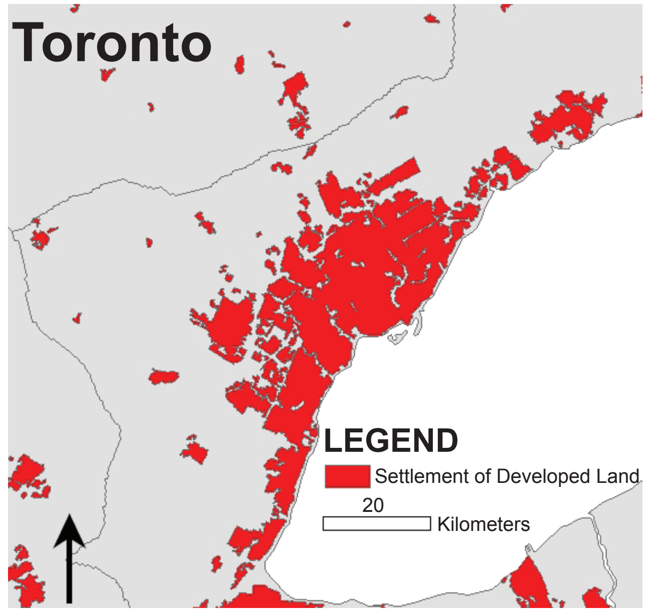

Figure 4. Toronto, Canada showing the area that is classified as settlement and developed land.
Source: Purdue University, Human-Environment Modeling and Analysis Laboratory and Natural Resources Canada.

In the United States, the Great Lakes basin watersheds of Lake Erie and Lake Michigan have the highest proportion (15.6% and 8.14%, respectively) of their watersheds consisting of impervious surfaces. Not surprisingly, the Lake Superior watershed contained the lowest proportion (2.92%) of impervious surfaces within the U.S. portion of the Great Lakes basin. It should be noted however, that on a per capita basis, the Lake Superior watershed ranked the highest (100.54 sq. km impervious surfaces per person) followed by the Lake Michigan, Erie, Ontario, and Huron watersheds (51.07, 47.36, 29.99, and 27.68 sq. km/person, respectively) (Table 1). One possible explanation for the trend seen in the Lake Superior watershed is that extensive road networks were most likely built to reach fairly remote locations with low populations, and the large amount of summer homes present in the Upper Peninsula of Michigan are only inhabited seasonally. Thus, the owners of these seasonal homes may not be counted as residents of these Upper Peninsula counties by the U.S. Census.

	Superior	Michigan	Huron	Erie	Ontario
Impervious Surface area	1283	9871	3197	9006	2370
Percent of Watershed	2.92%	8.14%	7.37%	15.60%	6.50%
Per capita	100.54	51.07	27.68	47.36	29.99

Table 1. Total area (sq. km.) and proportion of watershed that contains impervious surfaces and the amount of impervious surface per capita (sq. m. per person) in the USA region for each Great Lakes watershed.
Source: Purdue University, Human-Environment Modeling and Analysis Laboratory.

The amount of impervious surfaces that are found within the Canadian portion of the Great Lakes basin watersheds are an underestimate of the actual amount of impervious surfaces present, because road networks and some developed open lands were not classified for inclusion in the “settled and developed lands” land use classification. However, the watersheds located within Canada can still be compared to one another to identify trends between the watersheds. The highest proportion (5.79%) of impervious surfaces was found in the Lake Ontario watershed, in which much of the impervious surfaces can be attributed to large cities (ex: Toronto) which are located within the watershed. The Lake Erie, Lake Huron, and Lake Superior watershed consisted of 2.25%, 0.65%, and 0.01% of their land area being covered with impervious surfaces, respectively (Table 2).

	Superior	Huron	Erie	Ontario
Impervious Surface area	12	606	539	1734
Percent of Watershed	0.01%	0.65%	2.25%	5.79%

Table 2. Total area (sq. km.) and proportion of watershed that contains impervious surfaces in the Canada portion of the Great Lakes region.
Source: Purdue University, Human-Environment Modeling and Analysis Laboratory.

Management Implications

Many solutions exist to mitigate ground surface hardening expansion or to retrofit existing impervious surfaces. Care should be taken to minimize the loss of ecological services due to increased imperviousness. For example, runoff from buildings can be controlled by green roofs, i.e. vegetated roofs, which have been shown to retain up to 80% of rainfall runoff for rainfall events of 2.54 cm (1 in) or less. Additionally, green roofs, as well as green pavements, which are able to reflect more of the sunlight, are also known to decrease the urban heat island effect if widely used. Another often overlooked part of impervious surfaces is parking lots. One study, conducted at Purdue University, estimated that parking lots occupied 4.97% of the urban areas in the states of Illinois, Indiana, Wisconsin, and Michigan (Davis *et al*. 2009). This, along with other studies (Wilson 1995, Shoup 1995), call for revisions of parking lot ordinances which include maximum parking lot size recommendation in an effort to reduce the parking lot to building footprint ratios. Other possibilities for mitigating the effects of impervious surfaces on runoff include the use of concrete and pavement that is permeable to water. One such example can be seen in the city of Chicago, Illinois, where alleyways between buildings are being resurfaced to increase infiltration and decrease runoff of rainwater during storm events (Hawkins-Cox 2008). The increased infiltration acts as a filter for the rainwater, thus decreasing the total amount of pollutants (via microbial and fungal metabolises) before entering Lake Michigan via groundwater flow. Lastly, planning at the city level should also be focused on the reduction of urban sprawl, the development of reliable public transportation systems, and an increased emphasis on urban infilling. If mitigation techniques like those described above are employed throughout the Great Lakes basin, ground surface hardening need not to increase at the rate of population growth.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada				X		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes: *The population data for Canada was on a sq. km. basis (http://geogratis.cgdi.gc.ca/), while the population data for the United States was by U.S. Census block group (www.census.gov). *Additionally, the impervious surface data for Canada (http://geogratis.cgdi.gc.ca/) could not be broken down into percent impermeability like the U.S. impervious surface data (www.mrlc.gov) could. Thus, all land classified as "settled and developed land" by the Ontario Ministry of Natural Resources was considered impervious surfaces.						

Acknowledgements

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Last Updated
State of the Great Lakes 2009

Water Withdrawals

Indicator #7056

Overall Assessment

Status: **Mixed**
Trend: **Unchanging**
Rationale: **The amount of water withdrawn from the Great Lakes continues to slowly decrease in large part due to shutdown of nuclear power facilities, advances in water efficiency in the industrial sector, and growing public awareness of resource conservation. Limiting withdrawal from the Great Lakes will protect the ecosystem of the entire basin.**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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 1% 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.

State of the Ecosystem

Water was withdrawn from the Great Lakes basin at a rate of 164 billion liters per day (43,292 million gallons per day (MGD) in 2004, with almost two-thirds withdrawn in the United States (106,836 million liters per day (MLD) (28,223 MGD)) and the remaining one-third withdrawn in Canada (57,046 MLD (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 14% 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 3,062 billion liters per day (809,117 MGD) (Fig. 1, GLC 2006).

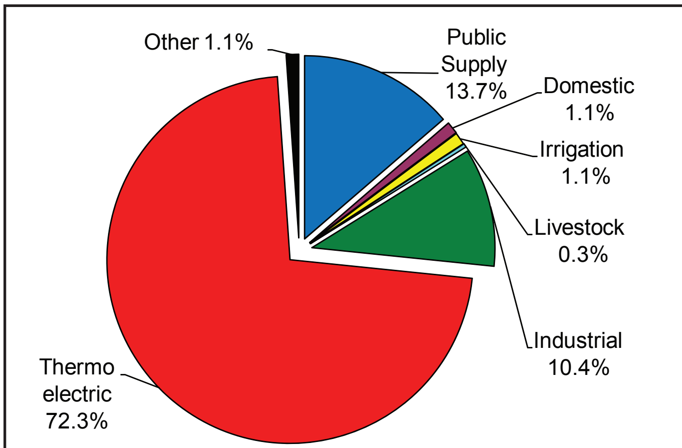

Figure 1. Water Withdrawals in the Great Lakes basin, by category as percentage of total, 2000.
Source: Great Lakes Commission (2004).

Withdrawal rates in the late 1990s were below their historical peaks and do not appear to be increasing at present. In the United States, 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.

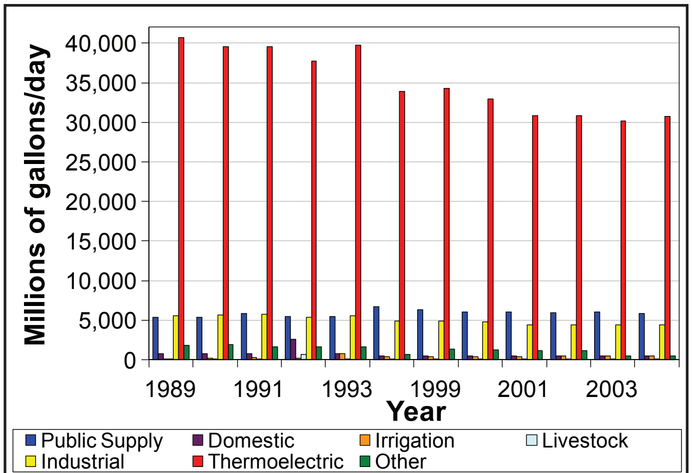

Figure 2. Great Lakes basin water withdrawals by category, 1989-1993 and 1998-2000.
Source: Great Lakes Commission, 1991-2004.

The majority of water withdrawn is returned to the basin through run-off and discharge. Approximately 5% is made unavailable, however, through evapotranspiration or 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 7,199 MLD (1,901 MGD) in 2004. 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 500,723 MLD (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.

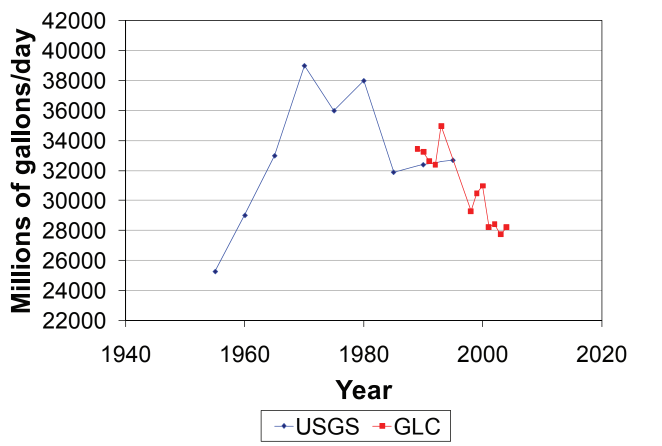

Figure 3. U.S. basin water withdrawals, 1950-2000.
Source: U.S. Geological Survey (1950-2000), Great Lakes Commission (GLC).

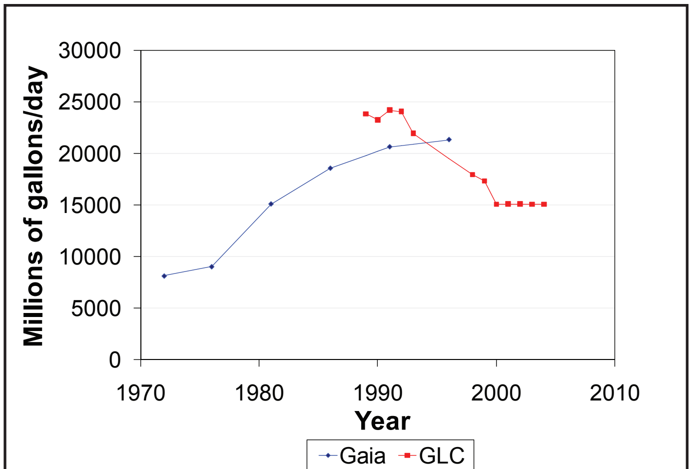

Figure 4. Canadian basin water withdrawals, 1972-2000.
Source: Gaia Economic Research Associates (1999) (based on data from Environment Canada and Statistics Canada), Great Lakes Commission (GLC).

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

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1 USGS estimates show water withdrawals in the U.S. Great Lakes watershed increasing from 95,691 MLD (25,279 MGD) in 1955 to a peak in the 136-148,000 MLD (36-39,000 MGD) range during the 1970 to 80 period, but dropping to the 117-121,000 MLD (31-32,000 MGD) range from 1985 to 1995. GLC reported U.S. water withdrawals in the 121-129,000 MLD (32-34,000 MGD) range for 1989 to 1993, and around 114,000 MLD (30,000 MGD) since 1998, with 117,261 MLD (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 30,798 MLD (8,136 MGD) in 1972 to 80,690 MLD (21,316 MGD) in 1996. GLC reported Canadian withdrawals of 79-91,000 MLD (21-24,000 MGD) in 1989 to 1993, around 64,000 MLD (17,000 MGD) for 1998 and 1999, and 57,046 MLD (15,070 MGD) in 2000.

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 in 1985 a voluntary agreement to manage the waters, called the Great Lakes Charter. The Charter required a basin-wide notification and consultation, for any new or increased diversion or consumptive use of the water resources of the basin which exceeds 19 million litres per day average in any 30 day period. Further, the U.S. Water Resources Development Act, 1986, amended in 2000, requires approval of diversions out of the basin by the eight Great Lakes governors. In 2001, the Great Lakes Charter was amended by Annex and was followed the "Great Lakes Basin Sustainable Water Resources Agreement" in 2005 that outlines administrative procedures pertaining to water diversions, consumption uses and withdrawals from the Great Lakes Basin – a virtual ban on diversions.

In Ontario, to enact the 2005 Agreement the *Ontario Water Resources Act* was amended in June 2007 by the *Safe-guarding and Sustaining Ontario's Water Act*. In the United States a *Great Lakes - St. Lawrence River Water Resources Compact* was developed, obtained ratification by the eight Great Lakes States and on October 3, 2008 the U.S. President signed a joint resolution of Congress to approve the Compact and enabling the Compact to become law as of December 8, 2008.

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 4,264 MLD (1,126 MGD) in 2004, making up 3% of total water withdrawals (GLC 2006). 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 was instituted in response to concerns over large-scale water diversions and bulk exports to markets such as the arid southwestern United States. 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.

The *Great Lakes - St. Lawrence River Water Resources Compact* has special provisions for communities and counties straddling the Great Lakes basin and does address existing diversions such as the Chicago diversion.

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 Europe are twice as high. However, economists have found that both residential and industrial water demand in the United States 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.

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).

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.

Management Implications

The Great Lakes-St. Lawrence Basin Sustainable Water Resources Agreement (Agreement) provides a framework for each province and state to pass laws that put in place new protections for basin waters. The good-faith Agreement bans new or increased water diversions out of the basin or from one Great Lakes watershed to another, with limited, strictly regulated exceptions The Agreement also strengthens water conservation through basin-wide objectives and programs in each state and province, establishes a stronger basin-wide environmental standard for regulating water uses, will build the information and science needed to support sound decision-making (e.g. through required water use reporting by water users), and strengthens regional collaboration (e.g. through the regional review of water management and conservation programs and significant diversion proposals and the periodic assessment of cumulative impacts) .

The Agreement is made binding in the United States through a companion interstate compact, the Great Lakes-St. Lawrence River Basin Water Resources Compact. On July 9, 2008, Michigan became the last of the eight Great Lakes states to sign the Compact into law. The United States Congress must endorse the Compact in order for it to become federal law. On October 3, 2008 the U.S.

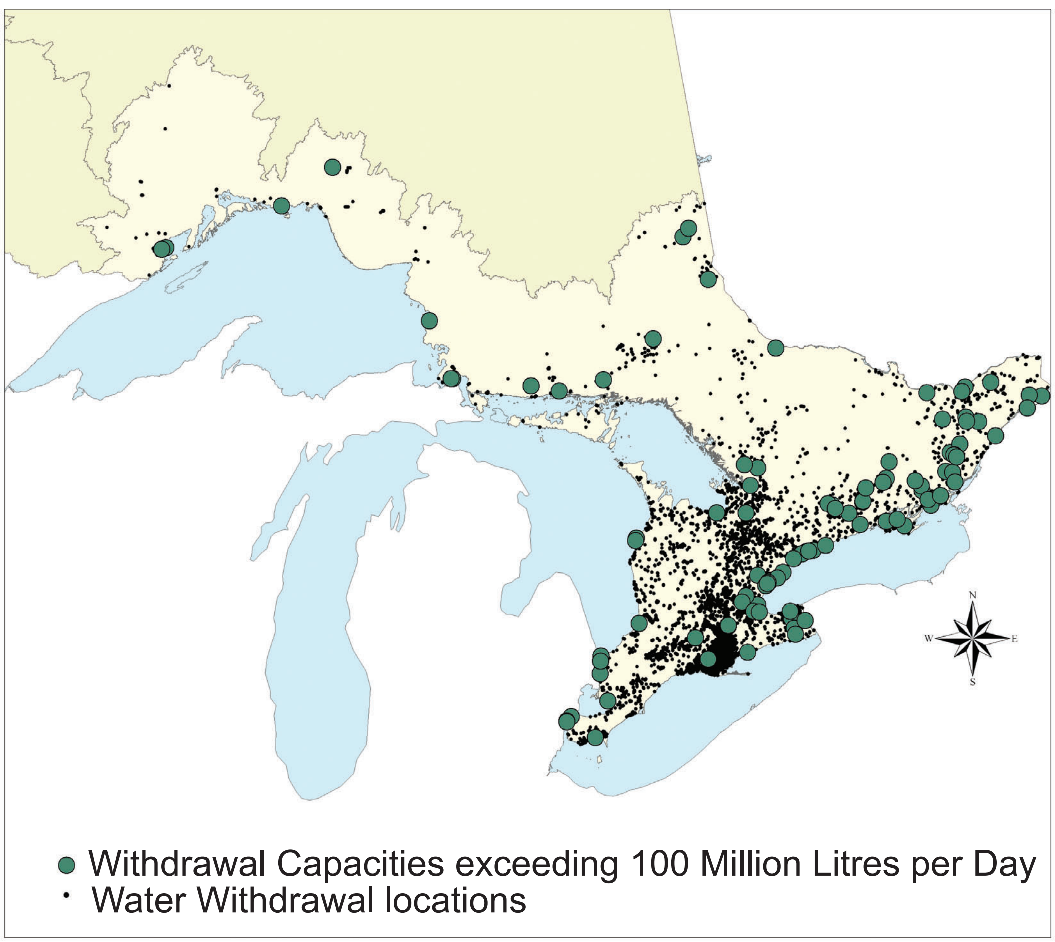

Figure 5. Permitted water withdrawal capacities in the Ontario portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources.

President signed a joint resolution of Congress to approve the Compact, enabling the Compact to become law as of December 8, 2008.

Comments from the author(s)

Water withdrawal data is already being compiled on a systemic basis, though 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. Provisions of the Agreement and the Compact will require that water users report monthly water use on an annual basis, hence improvements to water use information are anticipated. A regional water use information initiative has been established to facilitate these improvements.

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

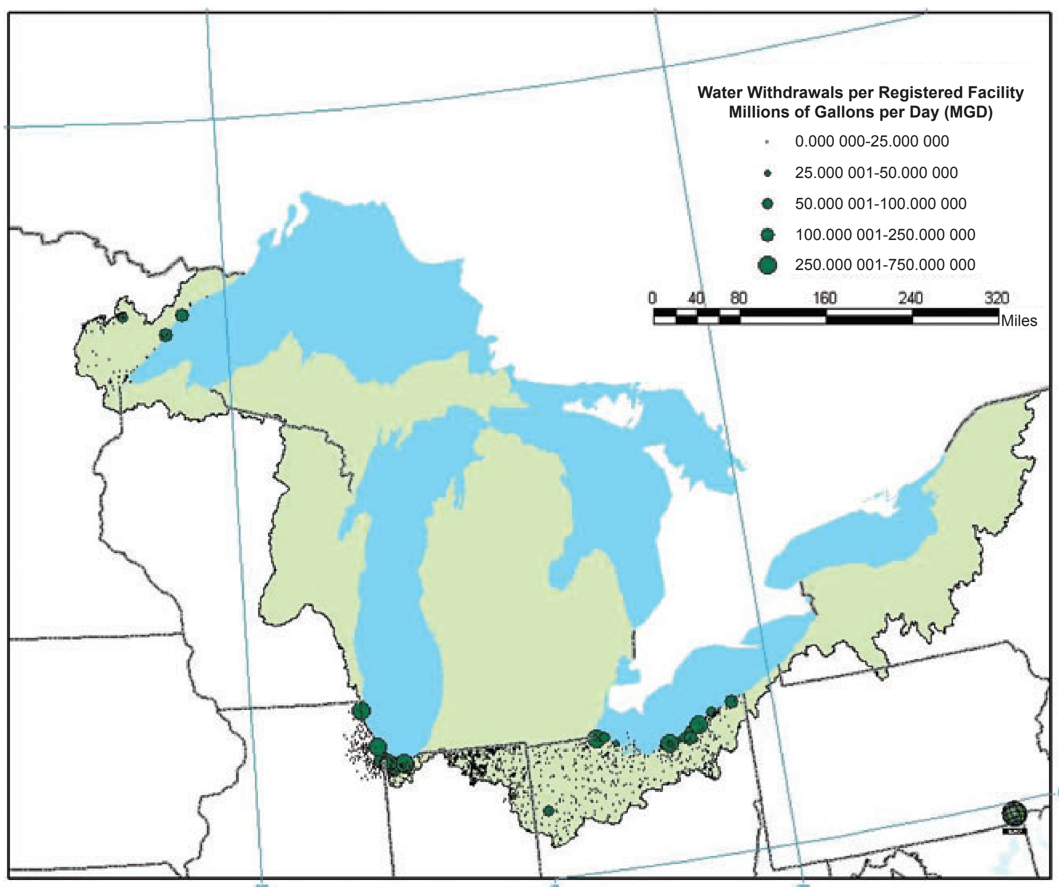

Figure 6. Map of Reported Water Withdrawals at Permitted or Registered Locations in Minnesota, Illinois, Indiana and Ohio.
Source: IL Department of Natural Resources, MN Department of Natural Resources, OH Department of Natural Resources, IN Department of Natural Resources 2009.

(Mills *et al*. 1993). The changes to the flow regime of water, through hydroelectric dams, internal diversions and canals, and 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. Through the Agreement and Compact, commitments have been made to the development of a regional science strategy and periodic cumulative impact assessments of basin water withdrawals, diversions and consumptive uses, at least every five years.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Contributor:
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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).

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Last Updated
State of the Great Lakes 2009

Energy Consumption
Indicator #7057

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose
- To assesses the energy consumed in the Great Lakes basin per capita
- 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 (GLWQA) (United States and Canada 1987).

State of the Ecosystem
Energy use per capita and total consumption by the commercial, residential, transportation, 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. portion 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 United States. 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).

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.

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 (Fig. 1). Electrical energy consumption per capita was fairly similar on both sides of the basin in 2000 (Fig. 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 (Fig. 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 Canadian side of the basin in 2002 was 930,400,000 Megawatt-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.

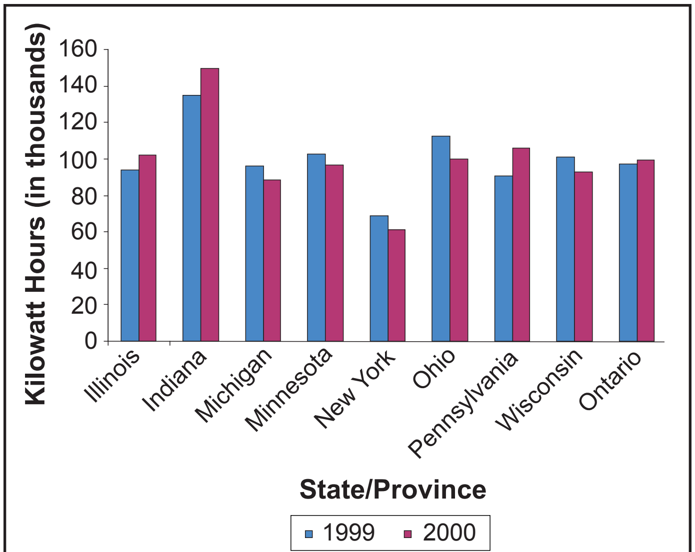

Figure 1. Total energy consumption per capita 1999-2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

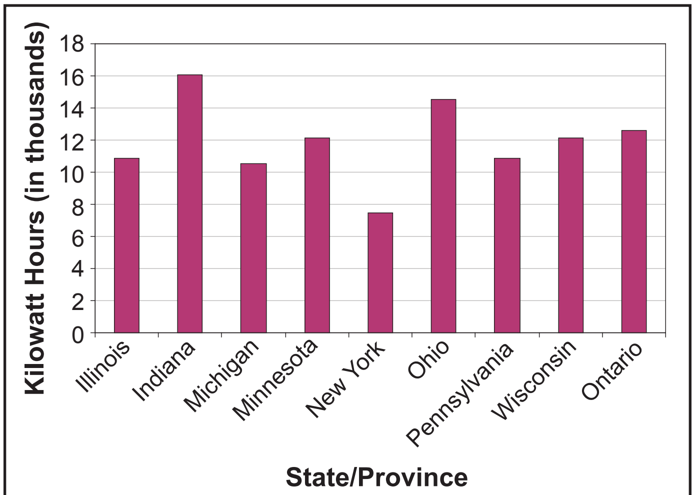

Figure 2. Electric energy consumption per capita 2000. 1 MWh = 1000 kWh.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

Total secondary energy consumption by the five sectors on the U.S. portion 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. portion of the 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. portions of the Great Lakes basin in 2000.

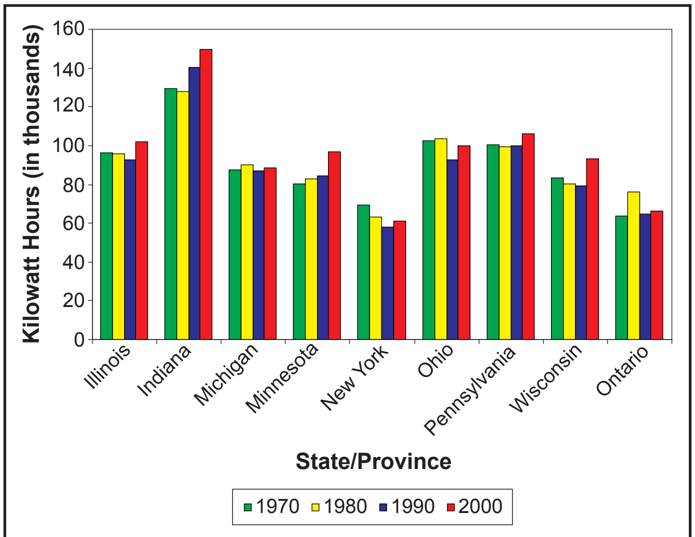

Figure 3. Total per capita energy consumption 1970-2000. 1 MWh = 1000 kWh.
Other energy sources include geothermal, wind, photo-voltaic and solar energy. The Ontario data do not include the electricity generation sector due to an absence of data for this sector until 1978.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

The commercial sector includes all activities related to trade, finance, real estate services, public administration, education,

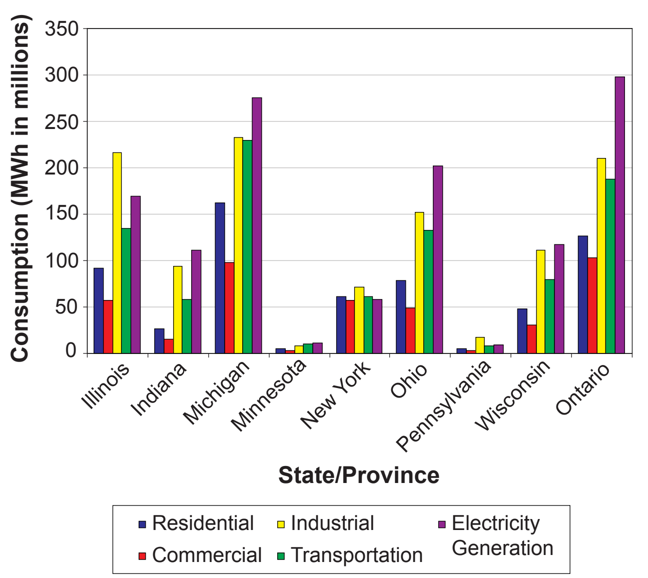

Figure 4. Secondary energy consumption within the Great Lakes basin by sector.
Note: all data are from 2000, although 2002 data from Ontario are discussed in the report.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

commercial services (including tourism), government and institutional living and is the smallest energy consumer of all the sectors in both Canada and the United States (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, in the U.S. portion 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 (Fig. 6).

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 Megawatt-hours (MWh).
Source: U.S. Energy Information Administration and Natural Resources Canada.

There was a 0.3% increase in total energy consumption by the Ontario residential sector between 2000 and 2002. In the U.S. portion 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% (Fig. 6).

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 noncommercial 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 United States, and aviation fuel, 6% in Ontario and 9% in the United States. 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 in the Canadian basin between 2000 and 2002.

The industrial sector includes all manufacturing industries, metal and non-metal mining, upstream oil and gas, forestry and construction, and in the U.S. portion of the basin also accounts for agriculture, fisheries and non-utility power producers. In the Canadian basin, 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,

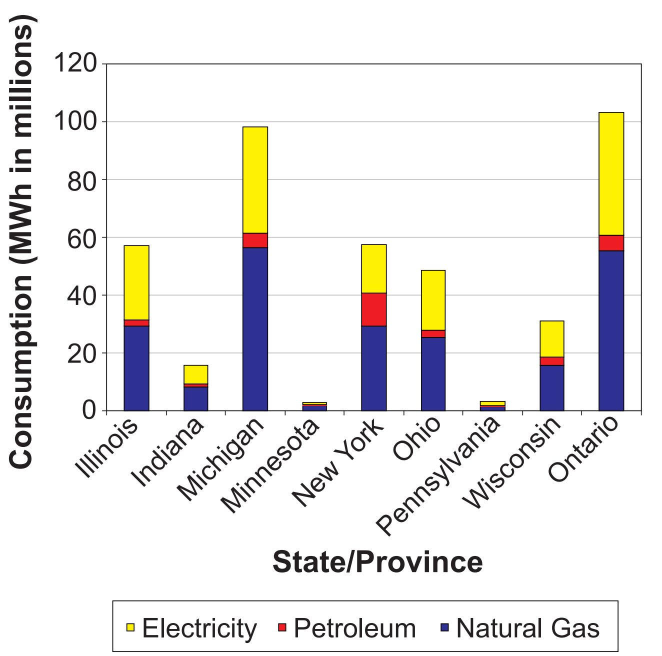

Figure 5. Commercial sector energy consumption by source, 2000.
Wood and coal were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

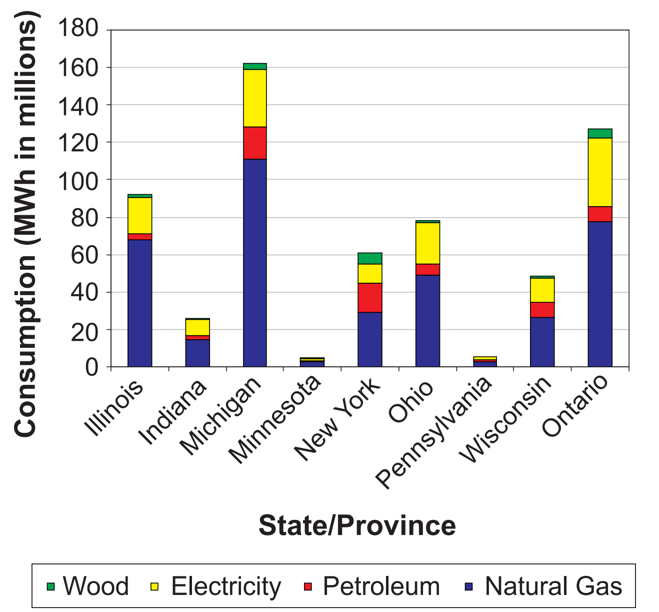

Figure 6. Residential sector energy consumption by source, 2000.
Coal, geothermal, and solar energy were minor sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

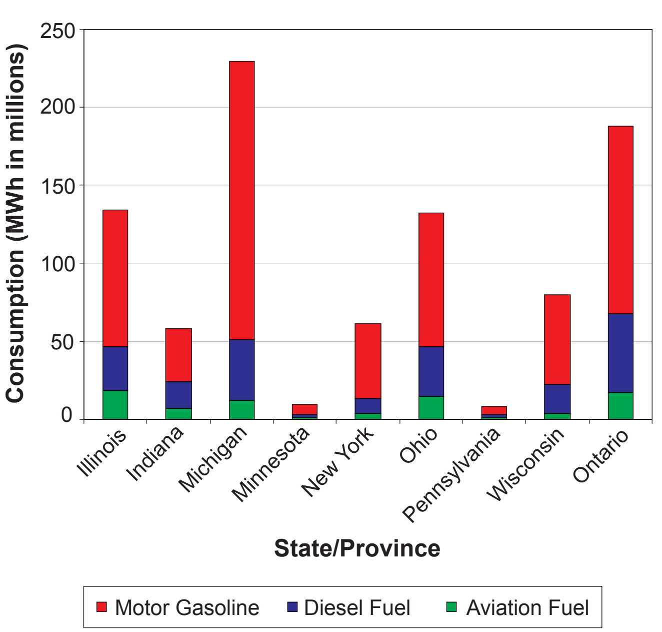

Figure 7. Transportation sector energy consumption by source, 2000.
Natural gas and electricity were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

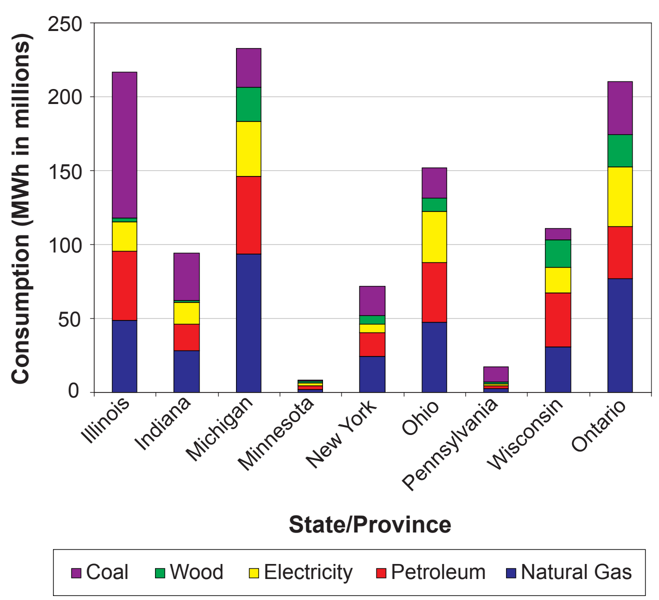

Figure 8. Industrial sector energy consumption by source, 2000.
Hydroelectric power was a minor source in this sector. U.S. data for wood include wood waste.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

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.

For the same sector, in the U.S. portion 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 in both the Canadian and U.S. portions 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. portion of the basin.

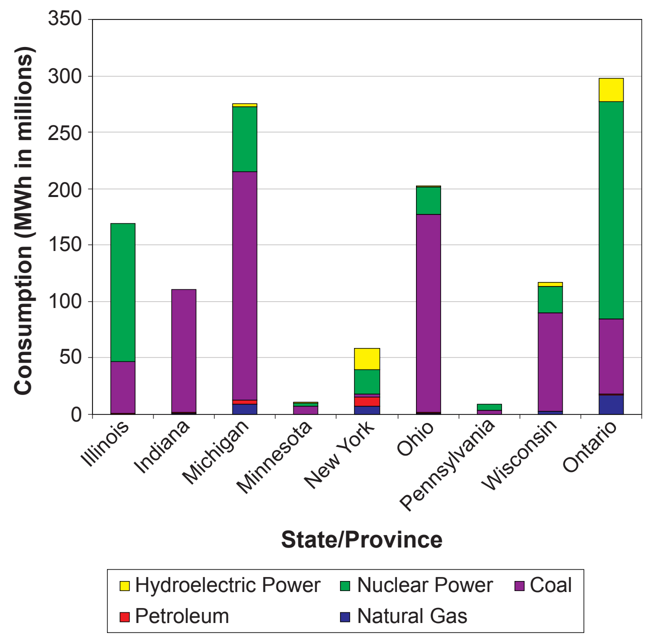

Figure 9. Electricity generation sector energy consumption by source, 2000.
Wood and wood waste were very minor energy sources in this sector.
Source: Energy Information Administration (2000) and Natural Resources Canada (2000).

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 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. portions 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 United States 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 through 2020 (http://www.nrcan.gc.ca/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 % in Ontario and 1% in Canada overall between 1995 and 2020. From 2010 to 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% of total power generation.

The pressures the United States currently faces will continue into the future, as the United States 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 United States with imports (largely from Canada) filling the gap. Forty percent 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/consumer/), 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 (U.S. EPA 2003). In addition to these programs, the Climate Change Plan for Canada challenges all Canadians to reduce their greenhouse gas emissions by one metric ton, 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 United States 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.

Comments from the author(s)

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 a 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 (from 1960 to 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 United States 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 United States 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 United States 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 United States 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.

Acknowledgments

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Last Updated
State of the Great Lakes 2005
[Editor's Note: Links to sources were updated for this publication when possible.]

Solid Waste Disposal*

Indicator #7060

**Proposed name change from Solid Waste Generation.*

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **This year the indicator report focuses only on disposal data in the United States instead of generation or recycling data. Disposal data were the most consistently collected by the counties/states in the United States. Generation and recycling data were available for Ontario. Over time, a change in disposal tonnages can be used as an indicator for solid waste in the Great Lakes. However, more consistent and comparable data would improve the value of this indicator.**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To assess the amount of solid waste disposed of in the Great Lakes basin
- To infer inefficiencies in human economic activity (i.e., wasted resources) and the potential adverse impacts to human and ecosystem health

Ecosystem Objective

Solid waste provides a measure of the inefficiency of human land-based activities and the degree to which resources are wasted. In order to promote sustainable development, the amount of solid waste disposed of in the basin needs to be assessed and ultimately reduced. Because a portion of the waste disposed of in the basin is generated outside of basin counties, efforts to reduce waste generation or increase recycling need to occur regionally. Reducing volumes of solid waste via source reduction or recycling is indicative of a more efficient industrial ecology and a more conserving society. This indicator supports Annex 12 of the Great Lakes Water Quality Agreement (GLWQA) (United States and Canada 1987).

State of the Ecosystem

Canada and the United States are working towards improvements in waste management by developing strategies to prevent waste generation and to reuse and recycle more of the generated waste. The data available to support this indicator are limited in some areas of the basin and not consistent from area to area. For example, while most states in the basin track the amount of waste disposed of in a landfill or incinerator located within a county, they may define the wastes differently. Some track all non-hazardous waste disposed of and some only track municipal solid waste. Because the wastes disposed of in each county in the basin were not necessarily generated by the county residents, per capita estimates are not meaningful to individual counties. Not all of the U.S. counties provide generation and recycling rates information. Canada provides estimates of waste generation rate for each of its provinces for residential, industrial/commercial, and construction and demolition sources. The summary statistics report for Canada also provided disposal data. The disposal data, however, included wastes that were disposed of outside the province, some of which is captured in the U.S. county disposal data. For this reason, generation and diversion estimates were used only for Ontario, and disposal data were used for the U.S. counties. Types of waste included in the disposal data are identified below.

Statistics for the generation of waste in Ontario were gathered from the Annual Statistics 2005 report (Statistics Canada 2005). More than 11 million metric tons (12 million tons) of waste were generated in Ontario in 2000 and slightly more than 12 million metric tons (13 million tons) were generated in 2002. These figures include residential wastes, commercial/industrial wastes, and construction and demolition wastes. Diversion information was also provided in the report and can be seen in Figure 1. In 2000,

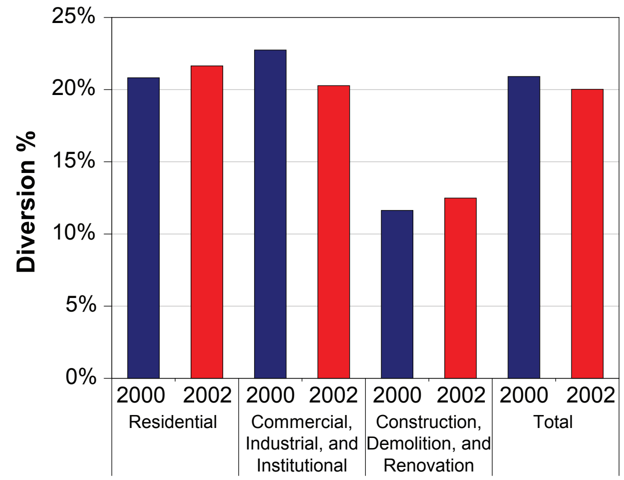

Figure 1. Ontario Waste Diversion Rates.
Source: Statistics Canada, Catalogue number 16-201XIE, Human Activity and the Environment. Annual Statistics 2005, Featured Article: Solid Waste in Canada.

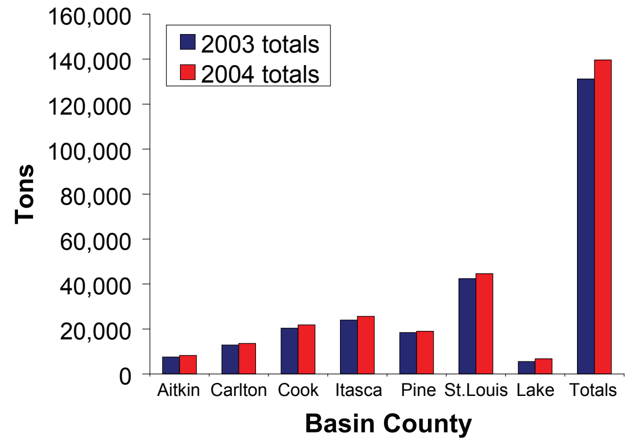

Figure 2. Minnesota Basin County Disposal.
Source: Minnesota Pollution Control Agency, Score Report, 2003 and 2004.

20.8% of the residential waste generated was diverted to recycling, and in 2002 that figure increased to 21.6%. The industrial/commercial recycling rate was 22.7% in 2000 and 20.2% in 2002. Finally, the construction and demolition recycling rate was 11.6% in 2000 and 12.5% in 2002. Ontario has a goal to divert 60% of its waste from landfill by 2008.

Minnesota Great Lakes basin counties provided data on the amounts of waste disposed of in the county as well as an estimate of the amount of waste buried by residents (on their own property). Data are provided in Figure 2. In 2003, 113,000 metric tons (125,000 tons) of waste were disposed of or buried in the seven basin counties in Minnesota. In 2004, there was a 5% increase to 120,000 metric tons (132,000 tons) disposed of or buried. Each county showed an increase in waste disposed. These figures only include municipal solid waste (not construction and demolition debris or other industrial wastes).

The Indiana Department of Environmental Management's data regarding amounts disposed of at permitted facilities were used to determine the total amount disposed of in each Indiana Great Lakes basin county. The data are illustrated in Figure 3. The disposal in 2004 was approximately 9% greater than in 2003. The 15 basin counties disposed of 2,240,000 metric tons (2,469,000 tons) of waste in 2004 and 2,018,000 metric tons (2,225,000 tons) in 2005. About 15% was generated outside of the counties where the disposal occurred in 2004. The data include municipal solid waste, construction and demolition wastes, and some industrial byproduct waste.

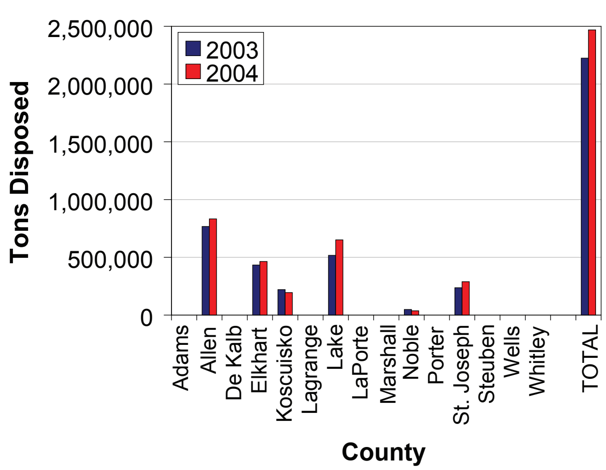

Figure 3. Indiana Basin County Disposal.
Source: Indiana Department of Environmental Management, Permitted Solid Waste Facility Report.

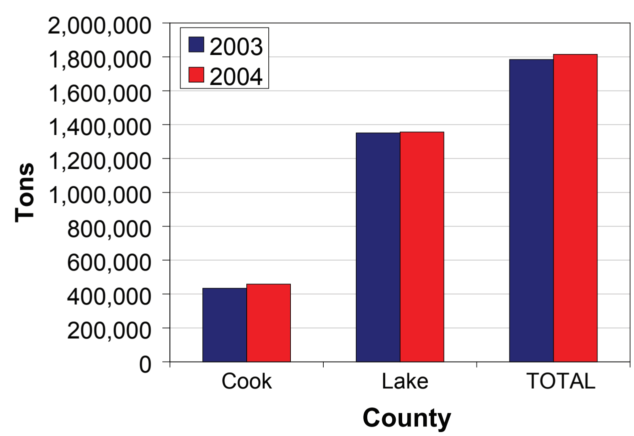

Figure 4. Illinois Basin County Disposal.
Source: Illinois Environmental Protection Agency, 2004 Landfill Capacity Report.

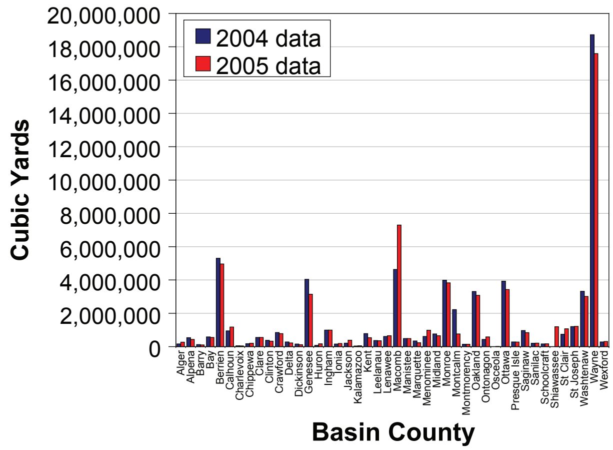

Figure 5. Michigan Basin County Disposal.
Source: Michigan Department of Environmental Quality, 2005 and 2004 Annual Report on Solid Waste Landfills.

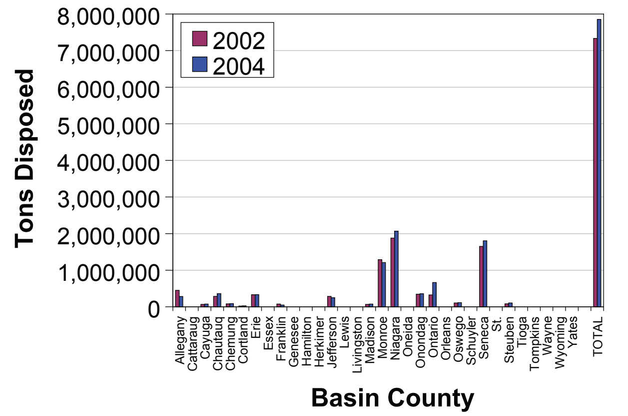

Figure 6. New York Basin County Disposal.
Source: New York State Department of Conservation Capacity data for Landfills and Waste to Energy Facilities.

The Illinois Environmental Protection Agency, Bureau of Land, reported the amounts disposed of in permitted landfills in the two Great Lakes basin counties. Data were compiled for 2004 and 2003 and are shown in Figure 4. There was less than a 2% change in total materials disposed. In 2004, 1,647,000 metric tons (1,815,000 tons) were disposed of, slightly greater than the 1,618,000 metric tons (1,784,000 tons) disposed of in 2003. The data include municipal solid waste, construction and demolition waste, and some industrial waste.

The Michigan Department of Environmental Quality reports on total waste disposed of in Michigan landfills in volume (cubic yards). General conversion factors to translate volume to mass (cubic yards to tons) could not be used because the waste totals include a variety of waste sources (municipal solid waste, construction and demolition debris, and some industrial byproducts). Data for the 83 Great Lakes basin counties were compiled and are presented in Figure 5. There was less than a 1% difference between the total volume (cubic yards) disposed of in 2004 and 2005 in these counties. The total for 2005 was slightly smaller. For both years, approximately 49 million cubic meters (64 million cubic yards) were disposed of in the 83 counties in the Great Lakes basin.

The New York Department of Environmental Conservation provided municipal solid waste disposal data for facilities located in the 32 Great Lakes basin counties for the years 2004 and 2002. The data are presented in Figure 6. There was an approximate 5% increase in waste disposed. The total waste disposed of was 7,124,000 metric tons (7,853,000 tons) in 2004 and 6,653,000 metric tons (7,334,000 tons) in 2002. These data include municipal solid waste only. More than 65% of the state's waste is managed in the basin counties.

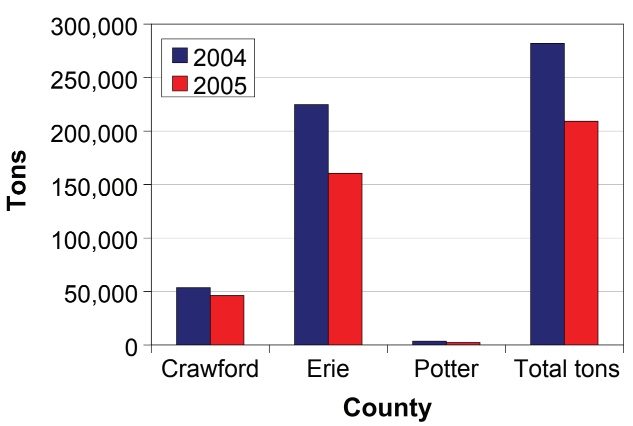

Figure 7. Pennsylvania Basin County Disposal.
Source: Pennsylvania Department of Environmental Protection Landfill Disposal Data.

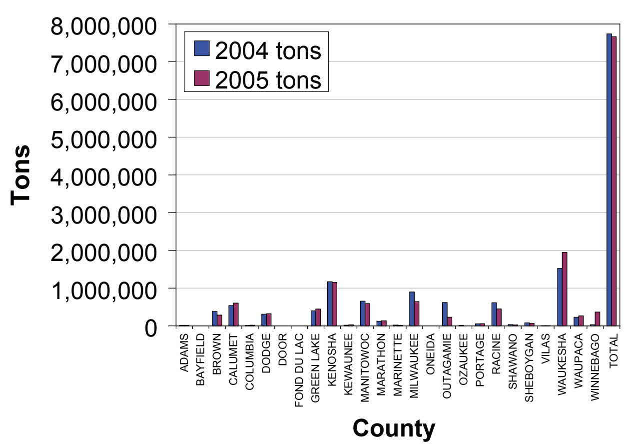

Figure 8. Wisconsin Basin County Disposal.
Source: Wisconsin Department of Natural Resources, Landfill Tonnage Report.

The Pennsylvania Department of Environmental Protection provided disposal data for the three Great Lakes basin counties. Municipal solid waste and construction and demolition debris are combined in these annual totals, which are presented in Figure 7. For 2004, 256,000 metric tons (282,000 tons) were disposed of in the three basin counties. There was a 25% decrease in waste disposed of in the counties in 2005 to 190,000 metric tons (209, 000 tons).

The Wisconsin Department of Natural Resources collects data on the amount disposed of in each facility located in the Great Lakes basin counties. Data were compiled for the 26 basin counties and are presented in Figure 8. In 2005, 6,952,000 metric tons (7,663,000 tons) of waste were disposed of, within 1 % of the total disposed of in 2004. Totals include a wide variety of wastes such as municipal solid waste, sludges, and foundry sand.

The Ohio Environmental Protection Agency collects data for waste disposed of in landfills and incinerators. The data for the 36 Great Lakes basin counties was compiled for 2003 and 2004 and are presented in Figure 9. There was an approximate 5% increase in waste disposed. More than 60% of these wastes disposed of in the counties came from outside the counties. The data include municipal solid waste, some industrial wastes, and tires. Construction and demolition debris is not included. In 2004, the 36 basin counties disposed of 7,976,000 metric tons (8,792,000 tons) and in 2003 7,561,000 metric tons (8,335,000 tons) were disposed.

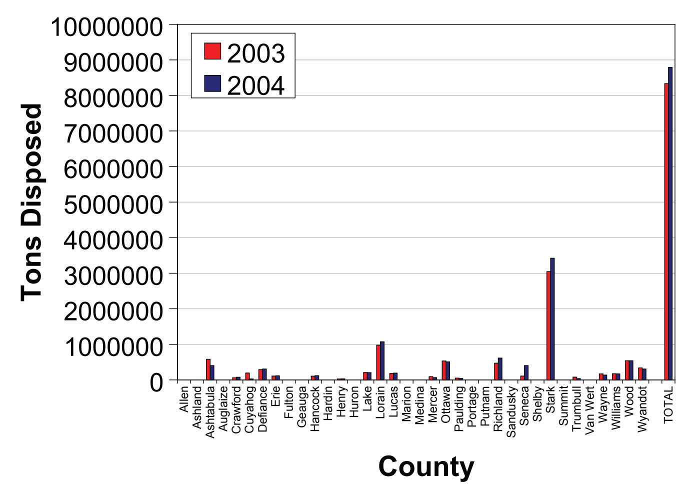

Figure 9. Ohio Basin County Disposal.
Source: Ohio Environmental Protection Agency, 2003 and 2004 Facility Data Reports.

Pressures

The generation and management of solid waste raise important environmental, economic and social issues for North Americans. Waste disposal costs billions of dollars and the entire waste management process uses energy and contributes to land, water, and air pollution. The U.S. Environmental Protection Agency (U.S. EPA) has developed tools and information linking waste management practices to climate change impacts. Waste prevention and recycling reduce greenhouse gases associated with these activities by reducing methane emissions, saving energy, and increasing forest carbon sequestration. Waste prevention and recycling save energy when compared to disposal of materials.

The state of the economy has a strong impact on consumption and waste generation. Municipal solid waste generation in the United States and Canada continued to increase through the 1990s, though the increase has been slower since 2000 (U.S. EPA 2003). Generation of other wastes, such as construction and demolition debris and industrial wastes is also strongly linked to the economy. The U.S. EPA is developing a methodology to better estimate the generation, disposal, and recycling of construction and demolition debris in the United States.

Because waste disposed of in the Great Lakes basin may be generated outside of the basin or moved around within the basin, efforts to reduce waste generation and increase recycling need to focus on a broader area, not just the basin. Continued collaboration of provincial, state, local, and federal efforts on both sides of the border is important for long term success.

Management Implications

The U.S. EPA supports a biennial study that characterizes the municipal solid waste stream and estimates the national recycling rate. The latest study (2003) estimates a 30.6% national recycling rate. The U.S. EPA has established a goal of reaching a 35% recycling rate by 2008. The 2003 study indicated that paper, yard and food waste, and packaging represent large portions of the waste stream. The U.S. EPA is concentrating its efforts on these materials and is working with stakeholders to determine activities that may support increased recovery of those materials. The U.S. government is also working to promote strategies that support recycling programs in general, including Pay-As-You-Throw (generators pay per unit of waste rather than a flat fee); innovative contracting mechanisms such as resource management (includes incentives for increased recycling); and supporting demonstration projects and research on various end markets and collection strategies for waste materials. The Great Lakes states and Ontario are also working to increase recycling rates and provide support for local jurisdictions. Each state with counties in the Great Lakes basin provides financial and technical support for local recycling programs. Many provide significant market development support as well.

Canada and the United States both support integrated solutions to the waste issue and look for innovative approaches that involve the public and private sectors. Extended Producer Responsibility (EPR), also known as Product Stewardship is one approach that involves manufacturers of products. EPR efforts have focused on many products, including electronics, carpets, paints, thermostats, etc.

Ontario's Waste Diversion Act was passed in 2002 and it created Waste Diversion Ontario (WDO), a permanent, non-crown corporation. The act gave WDO the mandate to develop, implement and operate waste diversion programs to reduce, reuse or recycle waste.

The City of Toronto has set ambitious waste diversion goals and reported a 40% diversion rate in 2005. The development of a green bin system (allowing residents to separate out the organic fraction of the waste stream from traditional recyclables) is credited for the high diversion rate achieved.

Improved and consistent data collection would help to better inform decision makers regarding effectiveness of programs as well as determining where to target efforts.

Comments from the author(s)

During the process of collecting data for this indicator, it was found that United States and Ontario compile and report on solid waste information in different formats. Future work to organize a standardized method of collecting, reporting and accessing data for both the Canadian and U.S. portions of the Great Lakes basin will aid in the future reporting of this indicator and in the interpretation of the data and trends. More consistent data may also support strategic planning.

Acknowledgments

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Other Resources

Illinois waste disposal data for the two basin counties were compiled from the Illinois Environmental Protection Agency, Bureau of Land's 2004 Landfill Capacity report found on their web site at: http://www.epa.state.il.us/land/landfill-capacity/2004/index.html. The two Great Lakes Basin counties are located in Illinois EPA's Region 2.

Indiana waste disposal data for the basin counties were compiled from the Indiana Department of Environmental Management's permitted solid waste facility reports found at http://www.in.gov/idem/programs/land/sw/index.html.

Michigan waste disposal data for the basin counties were compiled from the Michigan Department of Environmental Quality's Annual Report on Solid Waste Landfills. Data from the 2005 and 2004 studies were compiled. The author accessed the data via the Border Center's WasteWatcher web site (http://www.bordercenter.org/wastewatcher/mi-waste.cfm) to more easily search for the appropriate county-level data.

Minnesota municipal solid waste disposal data for the basin counties were compiled from the 2004 and 2003 SCORE data available on the Minnesota Pollution Control Agency's web site at: http://www.moea.state.mn.us/lc/score04.cfm. The SCORE report is a report to the Legislature. The main components of this report are to identify and target source reduction, recycling, waste management and waste generation collected from all 87 counties in Minnesota.

New York municipal solid waste disposal data for the basin counties were compiled from New York State Department of Environmental Conservation's capacity data for landfills and for "waste to energy" facilities available on their website at: http://www.dec.ny.gov/chemical/23723.html.

Ohio waste disposal data for the basin counties were compiled from Ohio Environmental Protection Agency's 2003 and 2004 facility data reports which are available on their web site at: http://www.epa.state.oh.us/dsiwm/pages/general.html.

Pennsylvania waste disposal data for the basin counties were compiled from the Pennsylvania Department of Environmental Protection, Bureau of Land Recycling and Waste Management's disposal data located on their web site at: http://www.depweb.state.pa.us/landrecwaste/cwp/view.asp?a=1238&Q=464453&landrecwasteNav=|.

Wisconsin municipal solid waste disposal data for the basin counties were compiled from the Wisconsin Department of Natural Resources, Bureau of Waste Management's Landfill Tonnage Report found on their website at: http://www.dnr.state.wi.us.

Last Updated
State of the Great Lakes 2007

Nutrient Management Plans
Indicator #7061

Overall Assessment

Status:	**Not Assessed**
Trend:	**Undetermined**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose
- To determine the number of Nutrient Management Plans
- 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 (GLWQA) United States and Canada 1987). 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 non-polluting, 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 five 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 (U.S. EPA) National Pollution Discharge Elimination System (NPDES) permit requirements. Individual states also have additional nutrient management programs. An agreement between U.S. EPA 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 basis due to the rapid changes in farming operations. This does not allow for an estimate of the total number of CNMPs. The U.S. EPA will be tracking PNP as part of the Status's NPDES program.

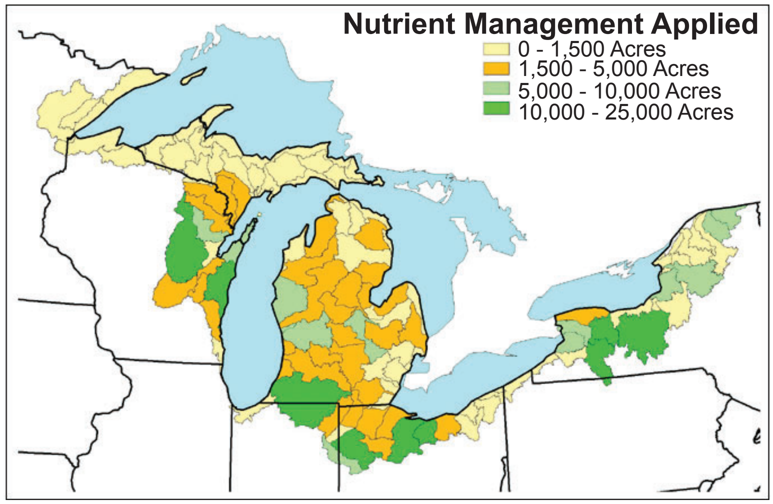

Figure 1. Annual U.S. Nutrient Management Systems total number of nutrient management plans developed annually for the U.S. portion of the basin, 2003.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Performance and Results Measurement System.

Figure 2 shows the number of Nutrient Management Plans by Ontario county for the years 1998 through 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.

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.

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.

Comments from the author(s)

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

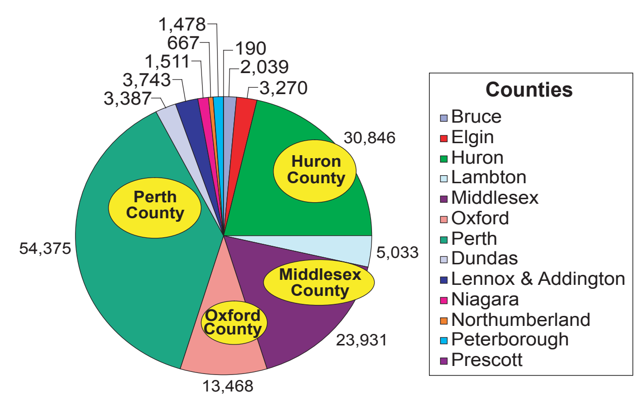

Figure 2. Nutrient Management Plans by Ontario county, 1998- 2002.
Source: Ontario Ministry of Agriculture and Food.

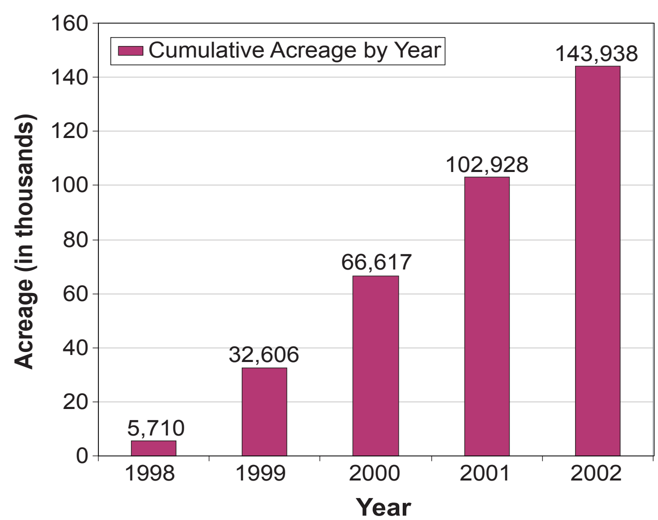

Figure 3. Cumulative acreage of Nutrient Management Plans for selected Ontario Counties in the basin.
Over 75% NMP acreages found in Huron, Perth, Oxford and Middlesex Counties.
Source: Ontario Ministry of Agriculture and Food.

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. The U.S. EPA 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.

Acknowledgments
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Sources
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Last Updated
State of the Great Lakes 2005

Integrated Pest Management
Indicator #7062

Overall Assessment

Status:	**Not Assessed**
Trend:	**Undetermined**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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 (GLWQA) (United States and Canada 1987).

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 on 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 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 (U.S. 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.

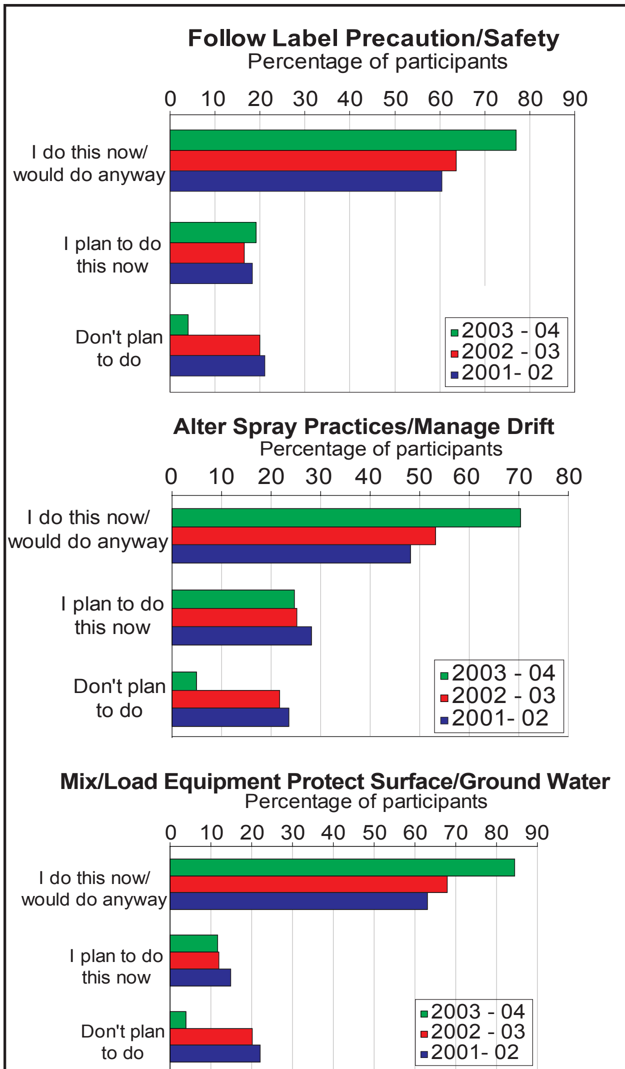

Figure 1. Ontario selected grower pesticide safety training course evaluation results from 2001-2004.
Source: Ontario Ministry of Agriculture and Food, Ontario Ministry of the Environment (OMOE) and the University of Guelph.

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 5,800 farmers who took pesticide certification courses over a three-year period (2001 to 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 significant 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.

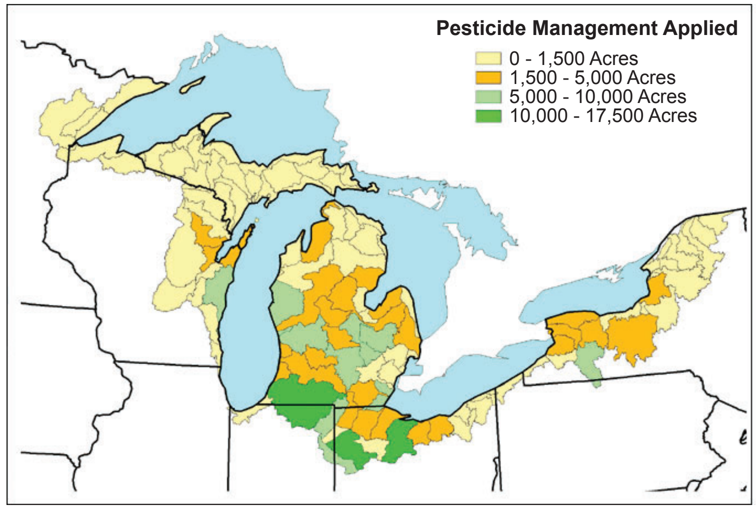

Figure 2. Annual U.S. Pesticide Management Systems Planned for 2003.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Performance and Results Measurement System.

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 IPM. This will require effective evaluations of existing policies and implementing programs for areas such as IPM. 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

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Last Updated

State of the Great Lakes 2005

Vehicle Use

Indicator #7064

Overall Assessment

Status: **Poor**
Trend: **Deteriorating**
Rationale: **Population growth and urban sprawl in the Great Lakes basin have led to an increase in the number of vehicles on roads, fuel consumption, and kilometers spent on the road by residents. Vehicle use is a driver of fossil fuel consumption, deteriorating road safety, and ecological impacts such as climate change and pollution.**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To assess the trends and amount of vehicle use in the Great Lakes basin;
- To infer the societal response to the ecosystem stresses caused by vehicle use.

Ecosystem Objective

This indicator supports Annex 15 of the Great Lakes Water Quality Agreement. An alternative objective is to reduce stress on the environmental integrity of the Great Lakes region caused by vehicle use.

State of the Ecosystem

A suite of indicators monitoring vehicle use, including the number of licensed registered vehicles and fuel consumption, is measured by governments in Canada and the United States to capture trends linked to fossil fuel consumption, road safety, and ecological impacts such as climate change and pollution. Figure 1 shows the estimated total distance traveled by vehicles on roads in Ontario during 1993-2005 and the number of licensed vehicles registered in Ontario (excluding trailers) for the same period. The number of licensed vehicles registered in Ontario rose from 6,329,052 in 1993 to 7,854,228 in 2005. Of greater significance is the estimated 125,102 million vehicle kilometers traveled (VKT) in Ontario in 2005, up 66% from 1993. The greatest increase in VKT occurred between 1999 and 2000 (an increase of 39%) followed by a 3% decrease in 2001. It is possible that recent record high prices for crude oil, which began climbing in late 2002, may be responsible for a slightly curbed VKT increase rate, and this may continue to affect VKT in the future. From these data, however, it is still evident that drivers in Ontario are increasingly spending more time on the road.

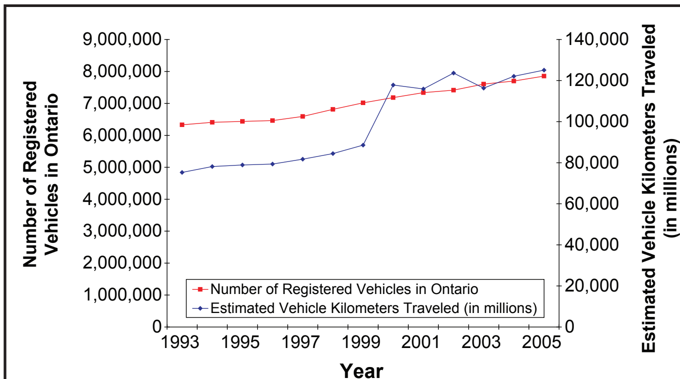

Figure 1. Number of Licensed Vehicles and Vehicle Kilometres Travelled in Ontario.
Source: Statistics Canada Canadian Vehicle Survey.

Figure 2 shows the estimated trends in registered vehicles, licensed drivers, and vehicle kilometers traveled in the Great Lakes states from 1994 to 2006. The number of registered vehicles increased approximately 13% during this time period, while the number of licensed drivers only increased 8%. These increasing trends are somewhat lower than national averages in the United States, which showed increases of 21% in the number of registered vehicles and 16% in number of licensed drivers. Just as in Ontario, VKT increased at a greater rate than the number of registered vehicles or licensed drivers. VKT increased in the Great Lakes states approximately 19% from 1994 to 2006, as compared to a 28% national increase. In 2006, U.S. residents in the Great Lakes states were driving about 6% more kilometers per vehicle than in 1994.

In Canada, the amount of energy used by the transportation sector between 1990 and 2004 increased 31%, from 1877.9 petajoules to 2465.1 petajoules. As a result, energy-related greenhouse gases (GHG) rose by 31%, from 135.0 megatonnes to 176.4 megatonnes. In that same time period, the number of vehicles rose 6% faster than the number of people (Government of Canada 2005).

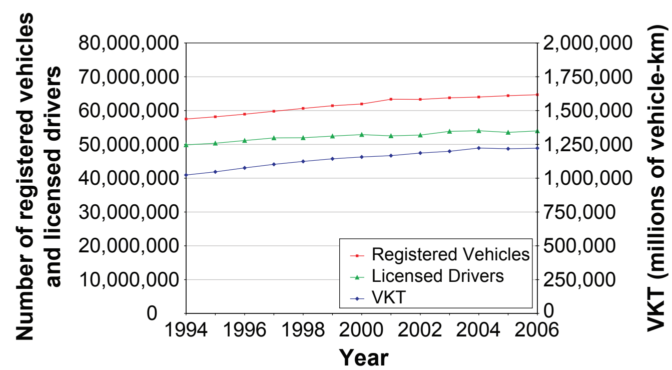

Figure 2. Number of Registered Vehicles, Licensed Drivers and Vehicle Kilometers Traveled in Great Lakes States.
Source: U.S. Department of Transportation, Federal Highway Administration. Office of Highway Policy Information. Highway Statistics Publications.

In Ontario, sale of motor gasoline increased by approximately 23% between 1994 and 2006 (Figure 3), on par with the national average. Gasoline sales rose from more than 12 billion liters to more than 15 billion liters between 1990 and 2006, and diesel fuel sales in Ontario alone doubled during the same period, from more than 2 billion to greater than 5 billion liters. This trend is driven by a rise in number of vehicles on Ontario highways, increased power of automobile engines, and the growing popularity of sports utility vehicles and large-engine cars (Statistics Canada 2008). In the Great Lakes states, fuel (gasoline and gasohol) consumption for vehicles increased by 15% on average from 1994 to 2006 (Figure 3), as compared to a 28% increase nationally in the United States.

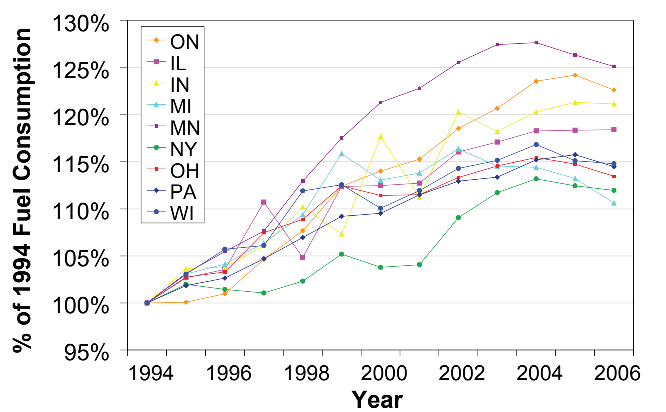

Figure 3. Fuel Consumption as a Percentage of 1994 Levels*.
*The data increase is based on initial 1994 Consumption Levels which differ across the areas studied.
Sources: Statistics Canada's Energy Statistics Handbook (2006) and U.S. Department of Transportation, Federal Highway Administration. Office of Highway Policy Information. Highway Statistics Publications.

Over the last decade, consumers have shown a strong preference for high-performance vehicles. Since 1999, the production of Sport Utility Vehicles (SUVs) has dominated the automotive industry, surpassing the output of both minivans and pickup trucks nationwide. For the period of January to September 2004, SUVs accounted for 18% of total light-duty vehicle manufacturing, which includes passenger cars, vans, minivans, pickup trucks and SUVs in Canada (Magnusson 2005). In the Great Lakes states, the registrations of private and commercially owned trucks, which include personal passenger vans, passenger minivans, and sport-utility vehicles, have increased 55% from 1994 to 2006. Private and commercially owned trucks now comprise about 38% of all registered vehicles in the Great Lakes states.

Pressures

Suburban development has become the predominant form of growth in the Great Lakes basin. The "mixed" assessment for the Air Quality indicator (#4202) can be directly linked to the increase in traffic congestion. As a major driver of ecological stress, vehicles are the single largest Canadian source of smog-causing GHG emissions. These emissions include nitrogen oxides (NO_x) and volatile organic compounds (VOCs) as well as carbon monoxide (CO), all which contribute contaminants to air and water systems (OMOE 2005). Such pollutants have been connected to respiratory problems and premature death. There is strong evidence that atmospheric deposition is a source of pollutants in storm water runoff and that this runoff reaches streams, rivers and other aquatic resources (International Joint Commission 2004). Congestion caused by automobiles and vehicle-related development also degrades the livability of urban environments by contributing noise, pollution, and fatalities. Positive trends in road use may also lead to further fragmentation of natural areas in the basin.

Management Implications

There is a need to reduce the volume and congestion of traffic in the Great Lakes basin. While progress has been made through less polluting fuels, emission reduction technologies, and economic tools such as the tax incentives that encourage the purchase of fuel-efficient vehicles (e.g., the American Tax for Fuel Conservation and the Canadian ecoAUTO Rebate Program), issues of urban sprawl must also be managed. Recent studies by the U.S. Environmental Protection Agency (U.S. EPA) found that infill development and re-development of older suburbs could reduce VKT per capita by 39% to 52%, depending on the metropolitan area studied (Chiotti 2004). The success of current strategies will assist managers and municipalities to protect natural areas, conserve valuable resources (such as agriculture and fossil fuels), ensure the stability of ecosystem services, and prevent pollution. Under the Kyoto Protocol, Canada is committed to reducing its GHG emissions by 6% below 1990 levels by the year 2010, even though the government may consider new targets.

Over the next 25 years, the number of people living in Ontario is expected to grow by approximately 3.8 million, the majority of which are expected to reside in the Great Lakes basin. In the Golden Horseshoe area alone, forecasts predict that the population of this area will to grow by 3.7 million from 2001 to 2031.

Improving urban transportation is the first investment priority. However, there is an acknowledgment that improving population growth forecasts, intensifying land use, revitalizing urban spaces, diversifying employment opportunities, curbing sprawl, protecting rural areas, and improving infrastructure are all part of the solution. Urban development strategies must be supported by positive policy and financial frameworks that allow municipalities to remain profitable, while creating affordable housing and encouraging higher density growth in the right locations. Further research, investment and action are needed in these areas.

Comments from the author(s)
For the purposes of this indicator, the total number of registered vehicles in Ontario excludes trailers, which are technically registered as vehicles in the province.

Canadian VKT data are based on a voluntary vehicle-based survey conducted by Transport Canada. The measure of vehicle-kilometers traveled does not take into account occupancy rates, which affect the sustainability of travel.

The records of state agencies that administer state taxes on motor fuel are the underlying source for most of the U.S. data presented in this report. Over the last several years, there have been numerous changes in state fuel tax laws and procedures that have resulted in improved fuel tax compliance, especially for diesel fuel. The improved compliance has resulted in increased fuel volumes being reported by the states to Federal Highway Administration (FHA).

U.S. VKT data are derived from the Highway Performance Monitoring System (HPMS). The HPMS is a combination of sample data on the condition, use, performance and physical characteristics of facilities functionally classified as arterials and collectors (except rural minor collectors) and system-level data for all public roads within each state.

Although data about VKT, registered vehicles, and fuel consumption were only available up to 2005 and 2006, the authors feel this indicator should be updated in future to examine potential shifts in vehicle use behaviors based on the recent rise in gasoline prices.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

Acknowledgments
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Other Resources

Ontario data for VKT was obtained from the Ministry of Transportation, Ontario's Ontario Road Safety Annual Reports. Original source of VKT data Statistics Canada, Canadian Vehicle Survey, Statistics Canada Catalogue No. 53-223-XIE . http://www.statcan.ca/english/freepub/53-223-XIE/53-223-XIE2007000.pdf

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Last Updated
State of the Great Lakes 2009

Wastewater Treatment and Pollution
Indicator #7065

Note: This is a progress report towards implementation of this indicator. It was last fully updated in 2007, with Canadian revisions incorporated in 2009.

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **Data to support this indicator have not been summarized according to quality control standards. Compilation of a comprehensive report on wastewater treatment and pollution in the Great Lakes will require a substantial amount of additional time and effort.**

Lake-by-Lake Assessment

Data summarization is incomplete and unavailable for analysis and assessment on an individual lake basin scale at this time.

Purpose
- To measure the proportion of the population served by municipal sewage treatment facilities
- To evaluate the level of municipal treatment provided
- To measure the percent of collected wastewater that is treated
- To assess the loadings of phosphorus, biochemical oxygen demand (BOD), ammonia and solids (and organic chemicals and metals, when possible) released by wastewater treatment plants into the water courses of the Great Lakes basin

Ecosystem Objective
The quality of wastewater treatment determines the potential adverse impacts to human and ecosystem health as a result of the loadings of pollutants discharged into the Great Lakes basin. The main objectives for assessing and reporting this indicator are to foster (1) reductions in the pressures induced on the ecosystem by insufficient wastewater treatment networks and procedures, and (2) the progression of wastewater treatment towards sustainable levels. Adequate maintenance of facilities and operational procedures are required to meet the objectives. This indicator supports Great Lakes Water Quality Agreement Annexes 1, 2, 3, 11 and 12 (United States and Canada 1987).

State of the Ecosystem
Background
Wastewater refers to the contents of sewage systems drawing liquid wastes from a variety of sources, including municipalities, institutions, industry and stormwater discharges. After treatment, wastewater is released as effluent into receiving waters such as lakes, ponds, rivers, streams and estuaries.

Wastewater contains a large number of potentially harmful pollutants, both biological and chemical. Wastewater systems are designed to collect and remove many of the pollutants using various levels of treatment, ranging from simple to very sophisticated. Effluents released from wastewater systems can still contain pollutants of concern, since even advanced treatment systems do not necessarily remove all pathogens and chemicals.

The following constituents, although not necessarily routinely monitored, are mostly associated with human waste and are present in all sewage effluent to some degree:

- biodegradable oxygen-consuming organic matter (measured as BOD)
- suspended solids (measured as total suspended solids (TSS)
- nutrients, such as phosphorus (usually measured as total phosphorus) and nitrogen-based compounds (nitrate, nitrite, ammonia, and ammonium, which are measured either separately or in combination as total nitrogen)
- microorganisms (which are usually measured in terms of the quantity of representative groups of bacteria, such as fecal coliforms or fecal streptococci, found in human wastes)
- sulphides
- assorted heavy metals
- trace amounts of other toxins and chemicals of emerging concern that have yet to be consistently monitored for in wastewater effluents

Municipal wastewater effluent is one of the largest sources of pollution, by volume, discharged to surface water bodies in Canada (CCME 2006). Reducing the discharge of pollution through wastewater effluent requires a number of interventions ranging from source control to end of pipe measures.

The concentration and type of effluent released into a receiving body of water depend heavily on the type of sewage treatment used. As a result, information regarding the level of wastewater treatment is integral in assessments of potential impacts on water quality. In both the United States and Canada, the main levels of wastewater treatment used include primary, secondary, and advanced or tertiary.

In the United States, *pretreatment* of industrial wastewater may be required to reduce levels of contaminants and to remove large debris before the waters are released to municipal treatment systems for regular treatment. U.S. federal regulations require that Publicly Owned Treatment Works (POTW) pretreatment programs include the development of local pretreatment limits for industrial pollutants that could potentially interfere with municipal treatment facility operations or contaminate sewage sludge. The U.S. Environmental Protection Agency (U.S. EPA) can authorize the states to implement their own pretreatment programs as well. Of the eight states that are part of the Great Lakes basin, Michigan, Minnesota, Ohio and Wisconsin currently hold an approved State Pretreatment Program (U.S. EPA 2006a).

In *primary* wastewater treatment, solids are removed from raw sewage primarily through processes involving sedimentation. This process typically removes about 25% to 35% of solids and related organic matter (U.S. EPA 2000).

Secondary wastewater treatment includes an additional biological component in which oxygen-demanding organic materials are removed through bacterial synthesis enhanced with oxygen injections. About 85% of organic matter in sewage is removed through this process, after which the excess bacteria

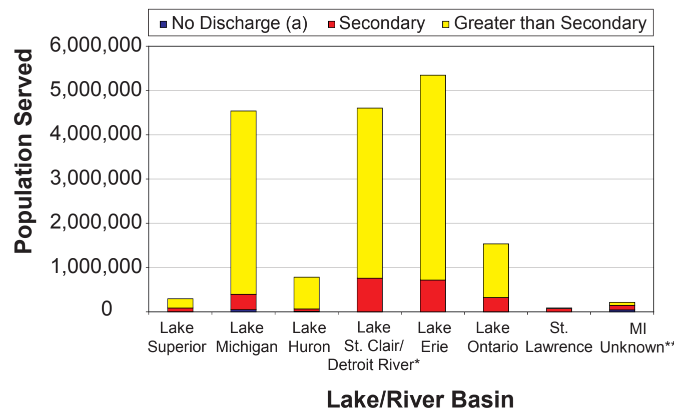

Figure 1. Population served by Publicly Owned Treatment Works (POTWs) by treatment level in the U.S. Great Lakes basin.
(a)= "No discharge" facilities do not discharge treated wastewater to the Nation's waterways. These facilities dispose of wastewater via methods such as industrial re-use, irrigation, or evaporation.
* Lake St. Clair and Detroit River watersheds are considered part of the Lake Erie basin.
** MI Unknown refers to the population served by facilities in the state of Michigan for which exact watershed locations are unknown, so the data could not be grouped with a specific lake basin. Population could potentially be distributed between the Lakes Michigan, Huron, or Erie.
Source: 2000 Clean Watershed Needs Survey.

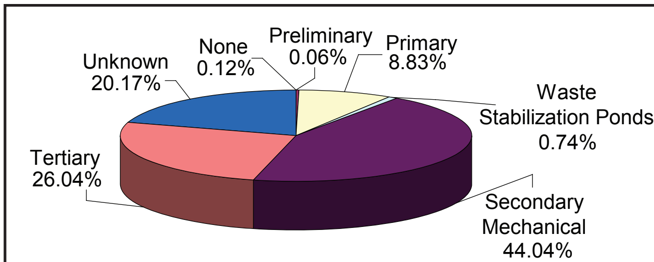

Figure 2. Percent of Canadian population served by wastewater treatment type in 2004.
Note: "Unknown" includes those using methods of wastewater treatment not provided by municipalities, such as septic systems.
Source: Gillian Walker, Water Resource Analyst, Sustainable Water Management Division, Environment Canada on Dec. 16, 2008. Based on results of the 2004 Municipal Water and Wastewater Survey and the 2001 Statistics Canada Census.

are removed (U.S. EPA 1998). Effluent can then be disinfected with chlorine prior to discharge to kill potentially harmful bacteria. Subsequent dechlorination is also often required to remove excess chlorine that may be harmful to aquatic life.

Advanced, or *tertiary*, levels of treatment often occur as well and are capable of producing high-quality water. Tertiary treatment can include the removal of nutrients, such as phosphorus and nitrogen, and essentially all suspended and organic matter from wastewater through combinations of physical and chemical processes. Additional pollutants can also be removed when processes are tailored to those purposes.

Levels of Treatment in the United States and Canada

In the United States, secondary treatment effluent standards are established by the U.S. EPA and have technology-based requirements for all direct discharging facilities. These standards are expressed as a minimum level of effluent quality in terms of biochemical oxygen demand measurements over a five-day interval (BOD_5), TSS and pH. Secondary treatment of municipal wastewater is the minimum acceptable level of treatment according to U.S. federal law unless special considerations dictate otherwise (U.S. EPA 2000).

Data on the level of treatment utilized in the United States are available from the Clean Water Needs Survey (CWNS). This cooperative effort between the U.S. EPA and the states resulted in the creation and maintenance of a database with technical and cost information on the 16,000 POTWs in the nation. According to the results of the 2000 CWNS, the total population served by POTWs in U.S. counties fully or partially within the Great Lakes basin was 17,400,897. Of this number, 0.7% received treatment from facilities that do not discharge directly into Great Lakes waterways and dispose of wastes by other means, 14.1% received secondary treatment, and 85.3% received treatment that was greater than secondary, making advanced treatment the type used most extensively (Fig. 1). These values do not include a possible additional 12,730 people who were reportedly served by facilities in New York for which watershed locations are unknown within the CWNS database.

In Canada, wastewater Treatment Plants (WWTPs) in Ontario also use primary, secondary, and tertiary treatment types. The processes are similar to those used in the United States, but Canadian regulatory

Treatment Type	Subtype	MWWS Response Options
Preliminary Treatment		None Grit Removal Screens/Bar Racks Skimming Other
Primary Treatment		None Primary sedimentation/clarification Plate/tube settlers Chemical precipitation/flocculation Other
Biological or Secondary Treatment Some systems may have more than one kind of treatment. Defined as "Treatment for the removal of most of the organic matter or to achieve significant biochemical oxygen demand and suspended solids reductions."	Mechanical Systems	None Conventional activated sludge Extended aeration activated sludge Pure oxygen activated sludge Other activated sludge Oxidation ditch Trickling filter Rotating biological contactor (RBC) Sequencing batch reactor (SBR) Other
	Lagoons or Waste Stabilization Ponds (WSPs)	None Aerated Aerobic Facultative Storage ponds Anaerobic Other
Advanced or Tertiary Treatment Defined as "Enhanced treatment to remove constituents, such as phosphorus and nitrogen, which may not be satisfactorily reduced from conventional secondary treatment."		None Polishing ponds Ammonia stripping or air stripping Biological nutrient removal of N and P Biological ammonia removal – nitrification only ($NH_3 \rightarrow NO_3$) Biological ammonia removal – nitrification and denitrification ($NH_3 \rightarrow N_2$) Biological phosphorous removal Chemical precipitation (P) Filtration Other

Table 1. Wastewater treatment types, definitions and response options used for the 2004 Municipal Water and Wastewater Survey conducted by Environment Canada.
Source: Environment Canada 2007. Municipal Water and Wastewater Survey (MWWS) Variable Description Document. Website available at: http://www.ec.gc.ca/water/MWWS/pdf/MWWS_VarDoc_Eng.pdf. Accessed on December 23, 2008.

emphasis is placed on individual effluent quality guidelines as opposed to mandating that a specific treatment type be utilized across a province. Table 1 includes a list of wastewater treatment types, definitions and examples of technologies that are used in Canada. This information is based on the survey response options from the Municipal Water and Wastewater Survey conducted by Environment Canada.

A complete distribution of population served according to level of treatment is not available at this time for the Great Lakes basin portion of Ontario. However, a distribution of the population served by each treatment type for all of Canada is available (Fig. 2), and it may serve as a very general estimate of levels of treatment to be found in the Canadian portion of the Great Lakes basin.

Tertiary or advanced treatment is the most common type of sewage treatment across the entire Great Lakes basin, as inferred from the distribution data in both Figures 1 and 2. This indicates the potential for high effluent water quality, but that can only be verified through analysis of regulatory and monitoring programs.

Condition of Wastewater Effluent in Canada and the United States: Regulation, Monitoring, and Reporting

Canada

Canada sets specific limits for each individual WWTP, regardless of the type of treatment used. Effluent guidelines for wastewater from federal facilities are to be equal to or more stringent than the established standards or requirements of any federal or provincial regulatory agency (Environment Canada 2004). The guidelines indicate the degree of treatment and the effluent quality applicable to the wastewater discharged from the specific WWTP. Use of the federal guidelines is intended to promote a consistent wastewater approach towards the cleanup and prevention of water pollution and ensure that the best control technologies practicable are used (Environment Canada 2004).

Table 2 lists the pollutant effluent limits specified for all federally approved WWTPs in Ontario. In general, compliance with the numerical limits should be based on 24 hour composite samples (Environment Canada 2004).

Pollutant	Effluent Limit
5 day Biochemical Oxygen Demand	20 mg/L
Suspended Solids	25 mg/L
Fecal Coliforms	400 per 100 mL (after disinfection)
Chlorine Residual	0.50 mg/L minimum after 30 minutes contact time; 1.00 mg/L maximum
pH	6 to 9
Phenols	20 micrograms/L
Oils & Greases	15 mg/L
Phosphorus (Total P)	1.0 mg/L
Temperature	Not to alter the ambient water temperature by more than one degree Centigrade (1°C)

Table 2. Canadian Pollutant Effluent Limits.
Source: Environment Canada (2004) Website available at : http://www.ec.gc.ca/etad/default.asp?lang=En&n=023194F5-1#specific.

In Ontario, wastewater treatment and effluents are monitored through a Municipal Water Use Database (MUD) by Environment Canada. This database uses a survey for all municipalities to report on wastewater treatment techniques. Unfortunately, the last complete survey is from 1999 and the data are not sufficient for use in this report. A current municipal water use survey is expected for release in 2007 and would be useful to examine treatment results within Canada.

United States

The United States regulates and monitors wastewater treatment systems and effluents through a variety of national programs. The U.S. EPA's Office of Wastewater Management promotes compliance with the Clean Water Act through the National Pollutant Discharge Elimination System (NPDES) permit program. These permits regulate wastewater discharges from POTWs by setting effluent limits, monitoring, and reporting requirements, and they can lead to enforcement actions when excessive violations occur. The U.S. EPA can authorize the states to implement all or part of the NPDES program, and all U.S. states in the Great Lakes region are currently approved to do so, provided they meet minimum federal requirements (U.S. EPA 2006a). This distribution of implementation power can create difficulties, however, when specific assessments are attempted across regions spanning several states.

Large-scale, national assessments of wastewater treatment have been completed in the past using BOD and dissolved oxygen (DO) levels as indicators of water quality. Since DO levels are proven to be related to BOD output from wastewater discharges (increased BOD loadings lead to greater depletion of oxygen and therefore lower DO levels in the water) historical DO records can be a useful indicator of water quality responses to wastewater loadings. According to a national assessment of wastewater treatment completed in 2000, the U.S. Great Lakes basin had a statistically significant improvement in worst-case DO levels after implementation of the Clean Water Act (U.S. EPA 2000). The study's design estimates also showed that the national discharge of BOD_5 in POTW effluent decreased by about 45%, despite a significant increase of 35% in the population served and the influent loadings. This improving general trend supported assumptions made in the 1996 CWNS Report to Congress that the efficiency of BOD removal would increase due to the growing proportion of POTWs using advanced treatment processes across the nation.

Unfortunately, comprehensive studies such as the examples listed above have not been conducted for pollutants other than BODs, and none have been completed to an in-depth level for the Great Lakes region. However, an extensive investigation of the Permit Compliance System (PCS) database is one way an evaluation of wastewater treatment could be accomplished. This national information management system tracks NPDES data, including permit issuance, limits, self-monitoring, and compliance. The PCS database can provide the information necessary to calculate the loadings of specific chemicals present in wastewater effluent from POTWs in the U.S. portion of the Great Lakes basin, providing the relevant permits exist.

Attempted Experimental Protocol for Calculating Pollutant Loadings from Wastewater Treatment Plants to the Great Lakes

The calculation of pollutant loadings from wastewater treatment plants was attempted for both the U.S. and Canadian portions of the Great Lakes basin during the compilation of this report. Although an extensive amount of data are available and have been retrieved, their summarization to an appropriate level of quality control is substantially difficult and is not complete at this time. The protocol followed thus far is outlined below.

United States

A list of all the municipal wastewater treatment facilities located within the U.S. Great Lakes basin, and their permitted pollutants, was compiled from the PCS database. A determination was made of the most consistently permitted contaminants, and effluent data for 2000 and 2005 were then retrieved for all facilities that monitored for those parameters. These pollutant parameters were referenced by various common names in the database, which complicated extraction of concise data. The resulting large quantity of data could not feasibly be summarized, however, due to internal inconsistencies that included differences in units of measurement, varying monitoring time frames, extreme outliers, and apparent data entry mistakes.

To decrease the amount of data requiring analysis, several specific facilities throughout the basin were chosen to serve as representative case studies for which total loadings estimates would be calculated. These facilities were chosen according to location within the basin (to ensure that all states and each Great Lake were represented) and by the greatest average level of effluent flow (because high flow facilities could potentially have the greatest environmental impact). Additionally, these flow values could be used to calculate loadings in the frequent cases where pollutant measurements were reported as a concentration as opposed to quantity. Fifteen facilities were selected for analysis, and corresponding effluent measurements for basic pollutants were extracted from the PCS database. Calculation of pollutant loadings, their percent change and the number of violations from 2000 to 2005 were attempted, but data quality issues undermine confidence in the calculated values.

Although total effluent loadings were difficult to calculate with confidence, government-generated historical records of effluent limit violations can provide some insight into the performance of U.S. Great Lakes wastewater treatment facilities. The Enforcement and Compliance History Online (ECHO) is a publicly accessible data system funded by U.S. EPA. It was used to obtain violation information by quarter over a three-year time span for the group of 15 U.S. facilities previously selected for loadings calculations. The resulting compliance data are presented in Figure 3 according to each pollutant for which violations of permitted effluent levels occurred during the 12 possible quarters under investigation from 2003-2006. Both basic violations of effluent limits and "significant" levels of non-compliance with permitted effluent limits are displayed. Chloride, fecal coliform, and solids violations were the most common, with copper, cyanide, and mercury having higher numbers of violations as well. Chloride, copper, mercury, and solids violations showed the most "significant" non-compliance with permitted levels.

Canada

In Ontario, wastewater treatment plants must report on the operation of the system and the quality of the wastewater treatment procedures on an annual basis to satisfy the requirements of the Ontario Ministry of Environment and the Certificate of Approval. Each report fulfills the reporting requirements established in section 10(6) of the Certificate of Approval made under the Ontario Water Resources Act (R.S.O. 1990, c. O.40). As a result of these requirements, effluent limit violations for BOD, phosphorus, and suspended solids should be available for future analysis. Data are too extensive to summarize at this time to a sufficient level of quality control.

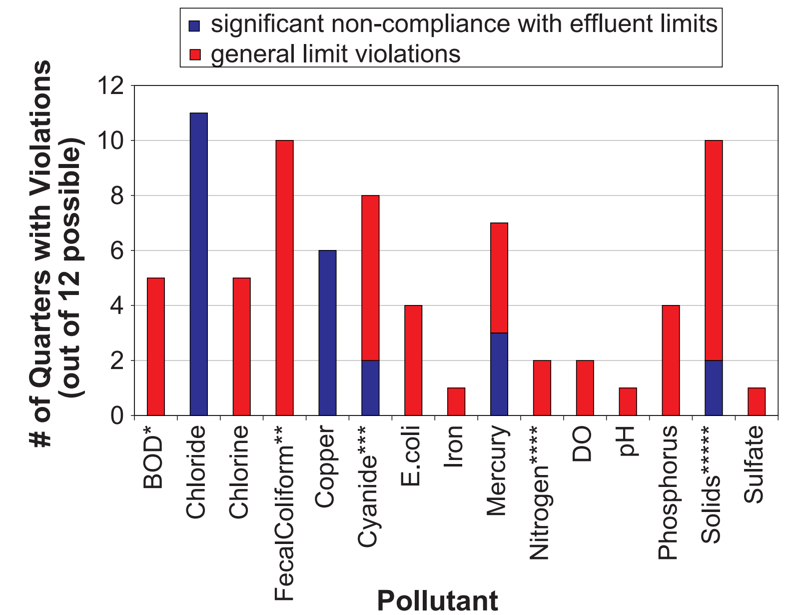

Figure 3. Total number of quarters with reported effluent limit violations by pollutant for selected U.S. facilities.
Data were compiled from 15 different facilities according to the total number of quarters that were in non-compliance of at least one pollutant effluent limit permit during 2003-2006.
* = combination of violations for 5-day BOD listed as total % removal and total
** = combination of violations for fecal coliform listed as general and analytical method "M-FC broth, 44.5C" totals
*** = combination of violations for cyanide listed as A and CN totals
**** = combination of violations for total nitrogen listed as N and as NH_3
***** = combination of violations for solids listed as total settleable, total dissolved, total suspended, and suspended % removal
Source: U.S. EPA (2006b), Office of Enforcement and Compliance Assurance. Website available at: http://www.epa.gov/echo/index.html.

Since results from the Municipal Water Use Database were not available at this time, 10 Canadian municipalities in the Great Lakes basin provided effluent data for analysis. Municipalities were randomly chosen based on their proximity to the Great Lakes and their population of over 10,000. Most of the chosen municipalities had one to three WWTPs in their jurisdiction, with a total of 22 Canadian treatment plants being examined for this indicator report. The WWTPs assessed were an even mixture of primary, secondary, and tertiary treatment plants. Data from 2005 annual reports for each WWTP were used to analyze wastewater treatment procedures and associated effluent quality, with special focus on BOD, phosphorus, suspended solids and *E. coli*.

These parameters are regulated by most WWTPs, and current targets exist to minimize environmental and health impacts. For example, Ontario WWTPs have a target of 50% for the removal of BOD, but levels must not exceed 20 mg/L in a five day span. The target for the removal of suspended solids is 70%, with a limit of 25 mg/L in a 24 hour sample period. Wastewater effluent limits for phosphorus in Ontario have been set at 1 mg/L. The *E. coli* concentration limit for WWTPs is generally <200 *E. coli* counts per 100 mL.

Out of the 22 Ontario WWTPs examined in 2005, levels of BOD, suspended solids, and *E. coli* concentrations collectively exceeded Ministry of the Environment Certificate of Approval limits six times. BOD levels were above the limit three times; total suspended solids exceeded the limits once, and *E. coli* concentrations exceeded the limit twice. Phosphorous levels did not exceed the limit for any WWTP in Ontario in 2005. There were six odor complaints from WWTPs throughout 2005, and these were from a primary treatment plant.

Pressures

There are numerous challenges to providing adequate levels of wastewater treatment in the Great Lakes basin. These include: facility aging, disrepair and outdatedness; population growth that stresses the capabilities of existing plants and requires the need for more facilities; new and emerging contaminants that are more complex and prolific than in the past; and new development that is located away from urban areas and served by decentralized systems (such as septic systems) that are much harder to regulate and monitor. The escalating costs associated with addressing these challenges continue to be a problem for both U.S. and Canadian municipalities (U.S. EPA 2004, Government of Canada 2002).

Management Implications

Despite demonstrated significant progress in wastewater treatment across the basin, nutrient enrichment, sediment contamination, heavy metals, and toxic organic chemicals still pose threats to the environment and human health. To maintain progress on these issues, and to ensure that current achievements in water pollution control are not overwhelmed by the demands of future urban population growth, governments should continually invest in wastewater treatment infrastructure improvements. In addition, investments are needed to control or mitigate polluted urban runoff and untreated municipal stormwater, which have emerged as prime contributors to local water quality problems throughout the basin (Environment Canada 2004).

In Canada, municipal wastewater effluent (MWWE) is currently managed through a variety of policies, by-laws and legislation at the federal, provincial/territorial and municipal levels (CCME 2006). This current variety of policies unfortunately creates confusion and complex situations for regulators, system owners and operators. As a result, the Canadian Council of Ministers of the Environment (CCME) has established a Development Committee to develop a Canada-wide strategy for the management of MWWE by fall 2007. An integral part of the strategy's development will be to consult with a wide variety of stakeholders to ensure that management strategies for MWWE incorporate their interests, expertise and vision. The strategy will address a number of governance and technical issues, resulting in a harmonized management approach (CCME 2006).

WWTPs are challenged to keep up with demands created by urban development. The governments of Canada and Ontario and municipal authorities, working under the auspices of the Canada-Ontario Agreement (COA) Respecting the Great Lakes Basin Ecosystem, have been developing and evaluating new stormwater control technologies and sewage treatment techniques to resolve water quality problems (Environment Canada 2004). Under COA, Canada and Ontario will continue to build on this work, implementing efficient and cost effective projects to reduce the environmental damage of a rapidly expanding urban population (Environment Canada 2004).

The presence of chemicals of emerging concern in wastewater effluent is another developing issue. Current U.S. and Ontario permit requirements are based on state or provincial water quality laws that are developed according to pollutants anticipated to exist in the community. This means the existence of new potentially toxic substances can be overlooked. For example, even in areas with a high degree of municipal wastewater treatment, pollutants such as endocrine-disrupting substances can inadvertently pass through wastewater treatment systems and into the environment. These substances are known to mimic naturally occurring hormones and may have an impact on the growth, reproduction, and development of many species of wildlife. Additional monitoring for these pollutants and corresponding protection and regulation measures are advised.

The methodologies used in previous U.S. national assessments of wastewater treatment could potentially be used to estimate loadings trends and performance measures for additional pollutants in the Great Lakes. The QA/QC safeguards included in such methods could lead to useful analyses of watershed-based point source controls. Substantial resources in terms of time and funding would need to be allocated in order to accomplish this task.

Comments from the author(s)
A number of challenges and barriers to the full implementation of this indicator report were encountered during its preparation. Included were:

Population estimates
The actual proportion of the entire population receiving municipal wastewater treatment is difficult to calculate. Several different population estimates exist for the region, but in the United States they were compiled by county, and therefore represent a skewed total for the population that actually resides within the boundaries of the Great Lakes watershed. GIS analysis of census data needs to be completed in order to obtain a more accurate estimate of the Great Lakes population.

Data availability
In Canada, only one year was assessed due to lack of available data. In future years, data from the Environment Canada MWWS will be incorporated. Prior to 1999, the survey was called Municipal Water Use and Pricing Surveys (MUD/MUP). In 2001, the survey format was changed and the name updated to the Municipal Water and Wastewater Survey (MWWS). The most recent data set for MWWS is for 2004, with the most recent water use report released in 2007. New data from the 2006 MWWS will be available in 2009, and additional surveys are planned for 2009 and 2011.

Loadings calculations
Several problems exist in the calculation of effluent loadings. For example, actual effluent flow is not consistently monitored in the United States. Although influent levels are obtainable for every facility, effluent levels might not be comparable, since a substantial volume may be removed during treatment processes. Because effluent flow data are necessary to calculate loadings from concentration values of pollutants, precise estimates of total loadings to Great Lakes waters may be next to impossible to obtain on a large scale without actual effluent flow data.

Consistency in implementation of analysis

Consistent guidelines and practices for the analysis of wastewater treatment in both the United States and Canada would be helpful. In the United States, data were compiled from several different databases, with population information derived from a separate source than effluent monitoring reports. In Ontario, data from 10 randomly chosen municipalities serving a population of 10,000 or greater were used for analysis, while in the United States, wastewater treatment facilities were chosen for "case studies." These approaches for analysis of wastewater treatment might provide a fragmented, and perhaps biased, view of the treatment patterns in the Great Lakes basin. In future years, data from the Environment Canada MWWS should be analyzed at a Great Lakes basinwide scale in order to provide a more accurate perspective on treatment patterns in the Canadian portion of the basin. The MWWS includes both population and wastewater treatment information in one source.

Consistency in monitoring and reporting

To successfully correlate wastewater treatment quality with the environmental status of the Great Lakes basin, a more organized monitoring program must be implemented. Although wastewater treatment plants provide useful monitoring information, they only report the quality of the effluent at that specific municipality, rather than the overall quality of the Great Lakes. Additionally, differences in monitoring requirements between Canada and the United States make assessments of the quality of wastewater treatment difficult on a basin-wide scale. Implementation of a more standardized, updated approach to monitoring contaminants in effluent and a standardized reporting format and inclusive database, accessible to all municipalities, researchers, and the general public, should be established for binational use. This would make trend analysis easier, and thus provide a more effective assessment of the potential health hazards associated with wastewater treatment for the Great Lakes as a whole.

Automated data processing

Considering all the difficulties encountered while attempting to adequately summarize the vast amount of U.S. effluent monitoring data contained in the PCS database, a logical solution would be an application that could automate accurate calculations. Such an application previously existed that was capable of producing effluent data mass loadings reports from the PCS database, and annual NPDES Great Lakes Enforcement reports were once compiled. However, the application used to calculate loadings was discontinued due to the modernization of the PCS system that is currently underway, and resources have not yet been available to extend the overhaul to this tool. Incorporating this component into the current modernization could take years due to various logistical problems, including the inherent quality assurance issues (James Coleman, personal communication). Despite these problems, the reinstatement of such a tool would solve the data summarization needs presented in this indicator report and could lead to an effective, comprehensive, and time-efficient analysis of pollutant loadings to the Great Lakes from U.S. wastewater treatment plants.

Further development of this indicator

The ultimate development of this progress report into a reportable Great Lakes indicator is necessary and would be possible in the near future if:

- Increased manpower and time could be dedicated to indicator development,
- Revisions were made to the proposed indicator that included a decreased scope, more realistic reporting metrics, and a less-strenuous reporting frequency,
- The data retrieval process were streamlined with appropriate quality controls, and
- A workgroup was created of members that held specific expertise regarding wastewater systems, treatment plant analytical methods, municipal infrastructure, permitting, and who had knowledge of and access to the relevant databases.

Note:

Immediately following the original preparation of this progress report, an assessment of municipal sewage treatment and discharges into the Great Lakes basin was compiled by Sierra Legal Defence Fund (known as Ecojustice Canada since 2007). The *Great Lakes Sewage Report Card* (2006) analyzes 20 Great Lakes cities and graded them on a variety of parameters relating to their sewage management systems. The full report is available to download online at, http://www.ecojustice.ca/publications/reports/the-great-lakes-sewage-report-card.

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Last Updated
State of the Great Lakes 2007

[Editor's note: Canadian portions of this progress report were revised and updated in 2009, following comments received after the 2008 State of the Lakes Ecosystem Conference (SOLEC). United States data and information have not been updated since the original 2007 publication date.].

Natural Groundwater Quality and Human-Induced Changes

Indicator #7100

Overall Assessment

Status: **Not Assessed**
Trend: **Not Assessed**
Rationale: **Some variability of groundwater chemistry occurs throughout the basin, however, little should occur within hydrogeologic units. Changes in groundwater quality due to anthropogenic activity will indicate the quality of groundwater for human consumption.**
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.

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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

An allegory for groundwater quality conditions in the Great Lakes basin is the Grand River watershed of Ontario. 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 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.

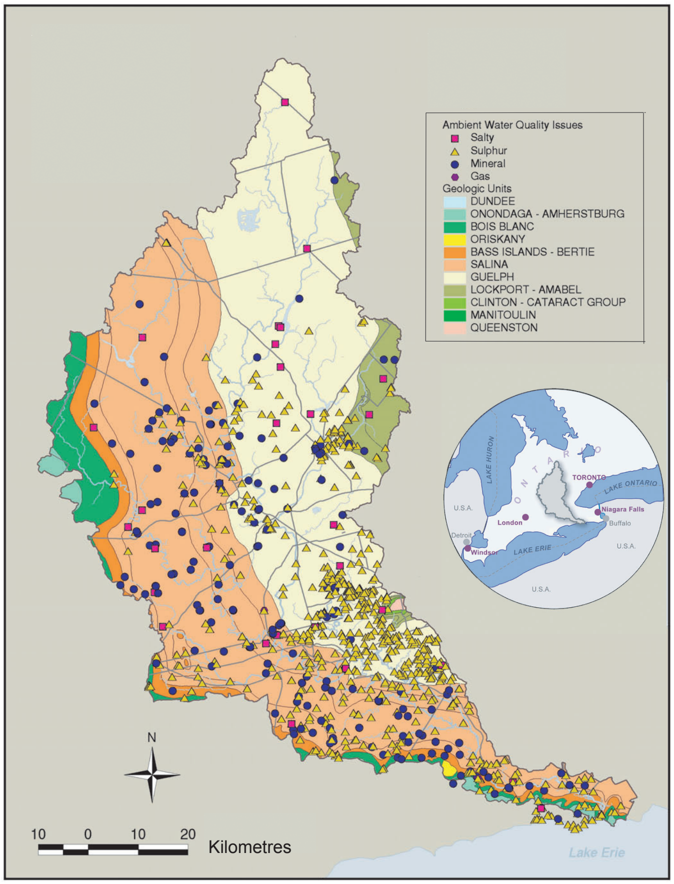

Figure 1. Bedrock wells with natural groundwater quality issues in the Grand River watershed.
Source: Grand River Conservation Authority.

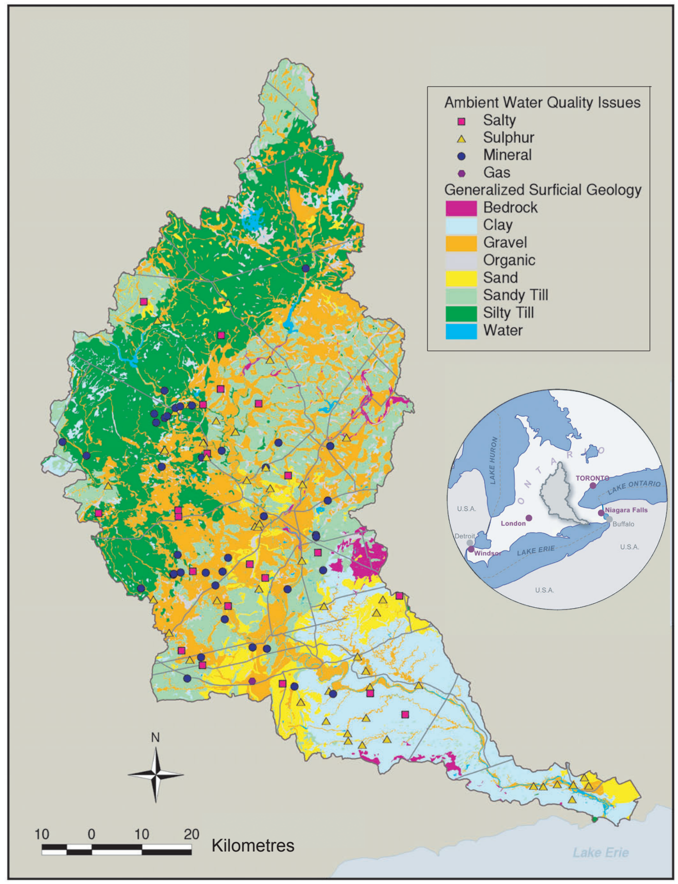

Figure 2. Overburden wells with natural groundwater quality issues in the Grand River watershed.
Source: Grand River Conservation Authority.

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 odor. 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.

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 high concentrations of sulphur (42%), minerals (34%), and salt (23%).

Human-Induced Changes to Groundwater Quality

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 de-icing 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.

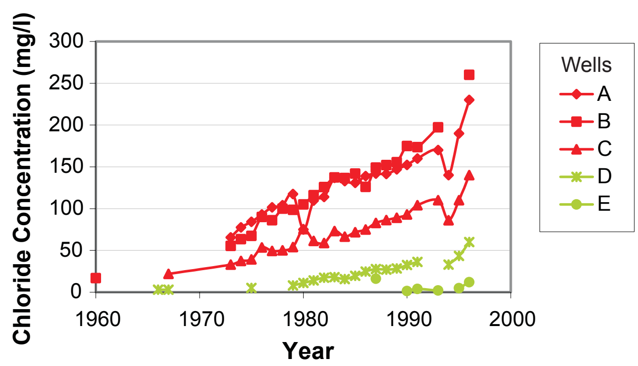

Figure 3. Chloride levels in selected groundwater wells in the Regional Municipality of Waterloo. Red indicates wells from an urbanized area/well field. Green indicates wells from a more rural area/well field.
Source: Stanley Consulting (1998).

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 established at 250 mg/L and 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 trichloroethylene (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 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

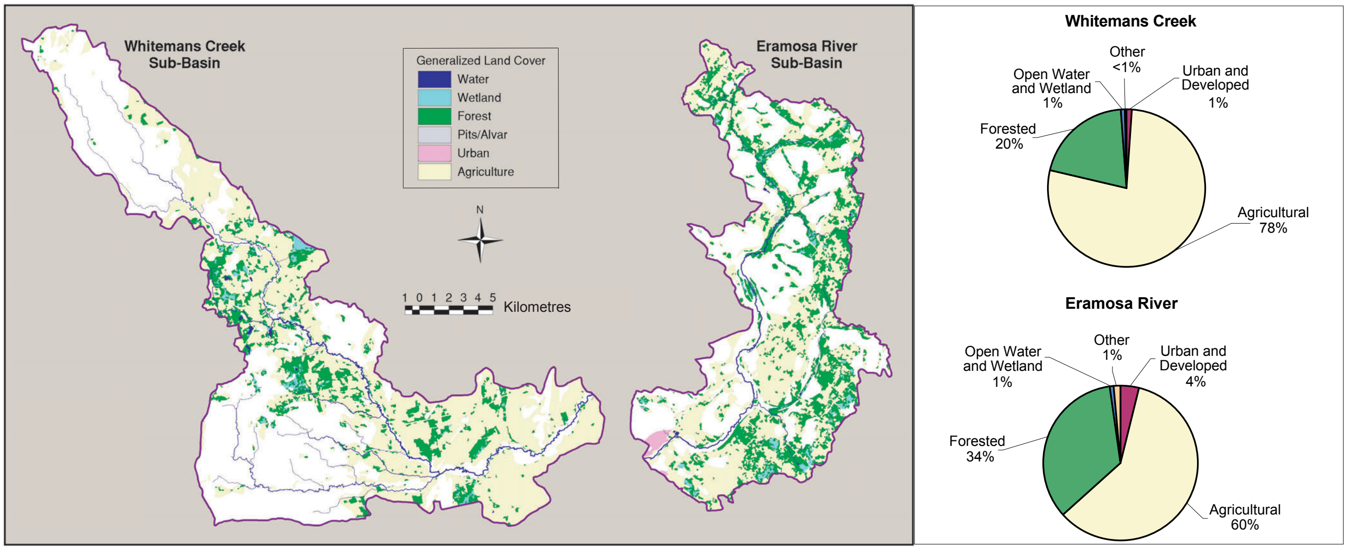

Figure 4. Land cover on moraine systems and areas that facilitate high to very high groundwater recharge of the Whitemans Creek and Eramosa River sub-watersheds: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority.

agricultural purposes with approximately 34% of the land being covered with forest (Fig. 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.

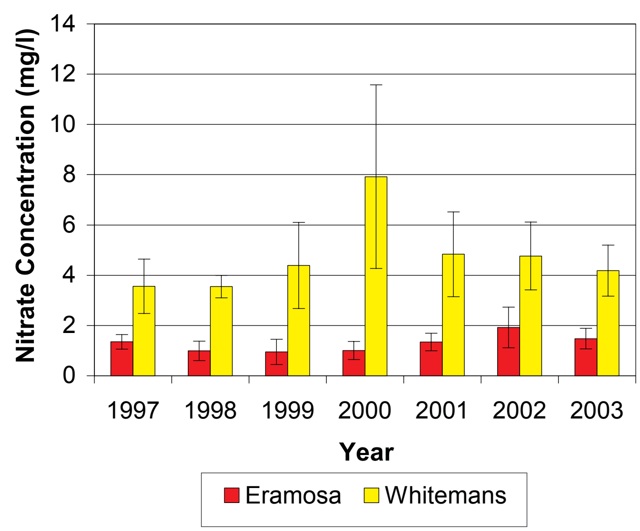

Figure 5. Average annual concentrations of nitrate measured in the Eramosa River and Whitemans Creek from 1997 to 2003. (Also shown on the bar graphs is the standard error of measurement.)
Source: Ontario Provincial Water Quality Monitoring Network (2003).

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. However, manure spreading on fields, runoff from waste disposal sites, and septic systems may all provide a source of bacteria to groundwater. Shallow wells are particularly vulnerable to bacterial contamination.

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 de-icing will lead to reductions in chloride contamination in groundwater. For example, the Regional Municipality 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.

Comments from the author(s)

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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

Acknowledgments

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Last Updated
State of the Great Lakes 2009

Groundwater and Land: Use and Intensity

Indicator #7101

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **Land use and water use and intensity, and the characteristics of the groundwater resources of the basin are interrelated.**
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.

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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 do not negatively impact groundwater supplies/resources.

State of the Ecosystem

Background

Land use and intensity have 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

An allegory for land use and water use intensity in the Great Lakes basin is the Grand River watershed of Ontario. 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 (Fig. 1). Urban development covers about 5% of the watershed area while forests cover about 17%. The largest urban centers, 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 (Fig. 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

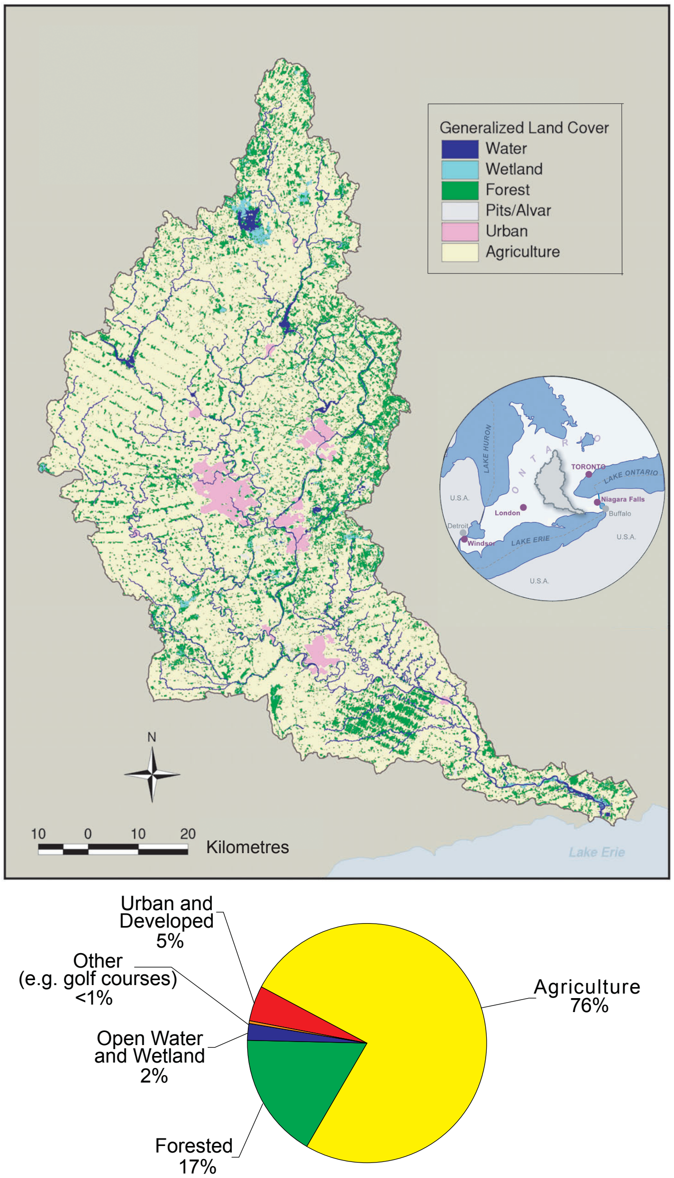

Figure 1. Land cover in the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority.

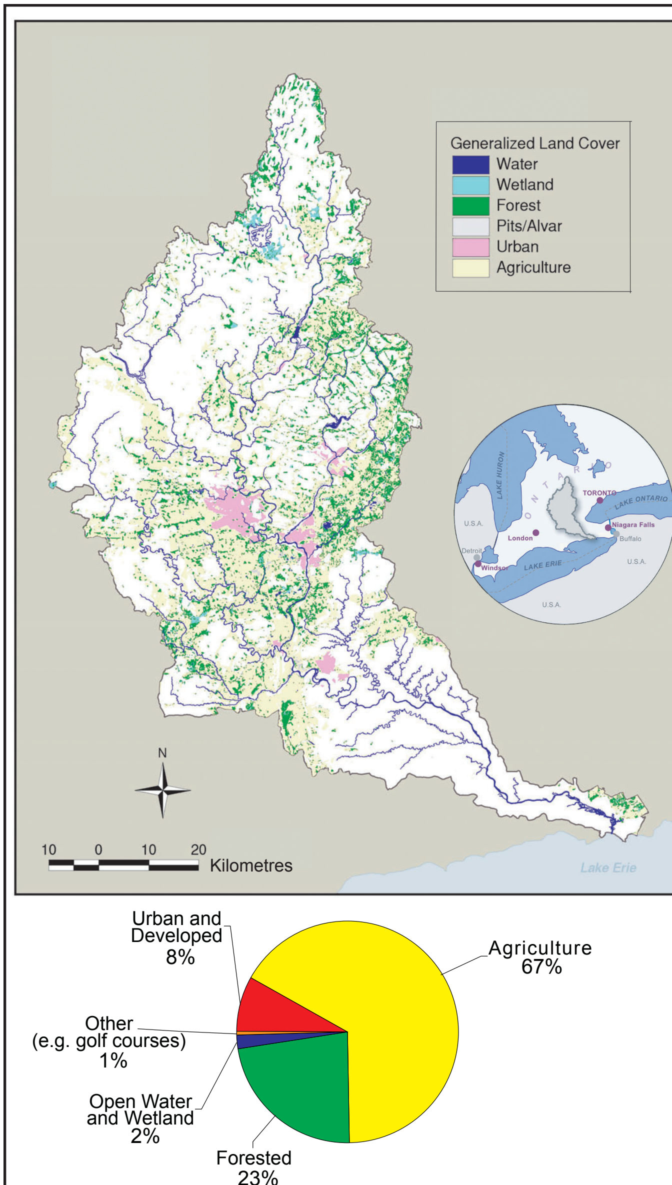

Figure 2. Land cover on moraine systems and areas that facilitate high or very high groundwater recharge of the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority.

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 (Fig. 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.

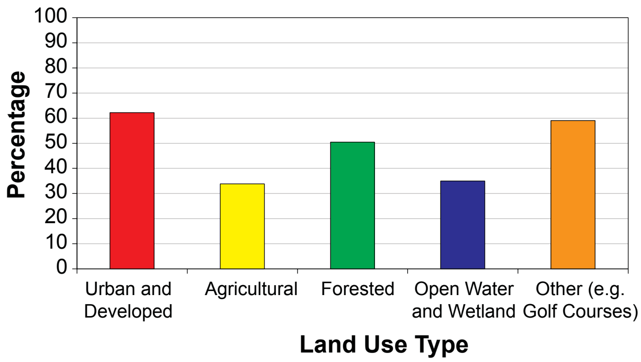

Figure 3. Percentage of land use type in significant recharge areas in the Grand River watershed.
Source: Grand River Conservation Authority.

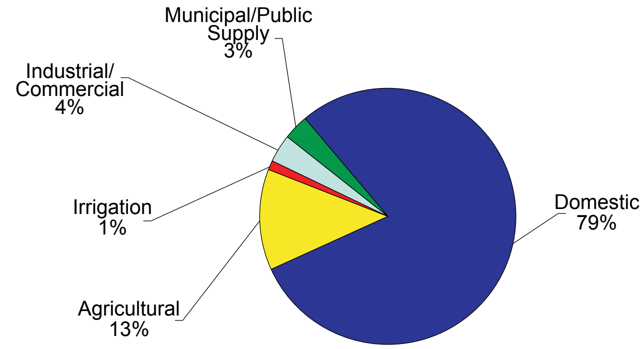

Figure 4. Distribution of groundwater wells by primary use in the Grand River watershed.
Source: Ontario Ministry of the Environment Water Well Database (2003).

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 (Fig. 3). Development is continuing in these sensitive areas. For example, of the total kilometers 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.

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 (Fig. 4). However, this represents only 3% of the total annual groundwater takings in the watershed (Fig. 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.

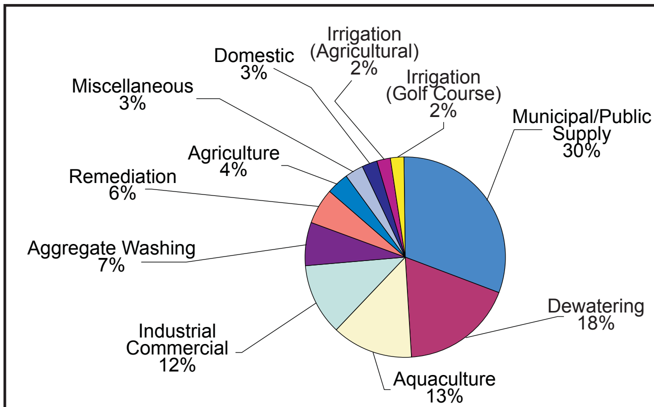

Figure 5. Percentage of total annual groundwater takings in the Grand River watershed from designated uses.
Source: Modified from Bellamy and Boyd (2004).

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 (Fig. 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 (Fig. 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 Fig. 7 represents conditions where average, below average and above average streamflow were measured. The 1987 to 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 (Fig. 8) likely contributes to greater demand for groundwater supplies.

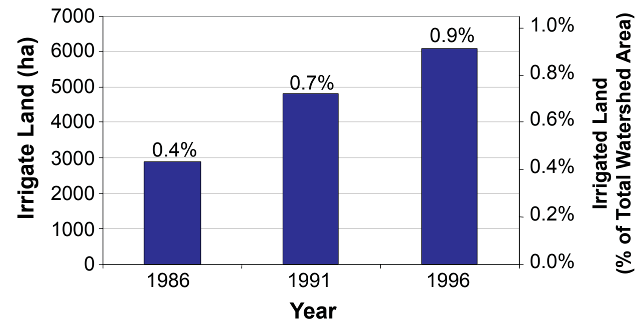

Figure 6. Changes in amount of irrigated land in the Grand River watershed (percentage of total watershed area irrigated).
Source: Statistics Canada data for 1986, 1991, and 1996.

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 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.

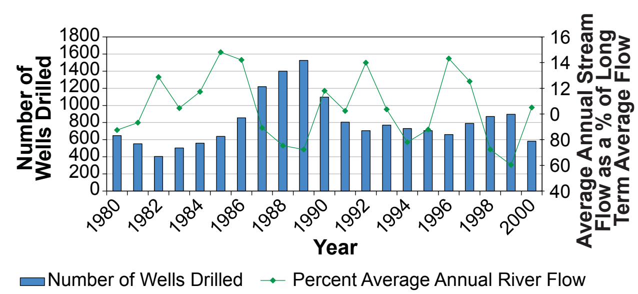

Figure 7. Number of new wells drilled each year (bars). Annual average stream flow (as a percentage on long term average) in the Grand River watershed illustrating below average, and average climatic conditions (green line).
Source: Ontario Ministry of the Environment Water Well Database (2003).

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 (Fig. 8). The biggest single users of groundwater are municipalities for municipal drinking water supplies, although industrial users, including aggregate and dewatering operations, use a significant amount of groundwater. Municipalities, watershed residents and industries will need to increase their efforts in water conservation as well as continue to seek out new or alternate supplies.

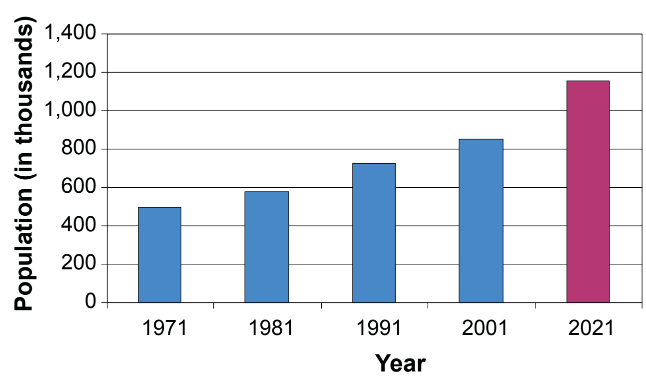

Figure 8. Estimated population in the Grand River watershed including future projections (burgundy bar).
Source: Dorfman (1997) and Grand River Conservation Authority (2003).

Climate influence on groundwater resources in the Grand River watershed cannot be underestimated. It is evident that during times with below average precipitation, there is increased demand for groundwater resources for both the natural environment and human uses. In addition, climate change will likely redistribute precipitation patterns throughout the year, which will likely impact groundwater resources in the watershed.

Management Implications

Land use and development have 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 focused 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.

Comments from the author(s)
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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments
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Last Updated
State of the Great Lakes 2009

Base Flow Due to Groundwater Discharge

Indicator #7102

Overall Assessment

Status:	**Mixed**
Trend:	**Deteriorating**
Rationale:	**It is estimated that human activities have detrimentally impacted groundwater discharge on at least a local scale in some areas of the Great Lakes basin and that discharge is not significantly impaired in other areas.**

Lake-by-Lake Assessment

Individual lake basin assessments were not prepared for this report.

Purpose

- To measure the contribution of base flow due to groundwater discharge to total stream flow
- 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, 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, quality 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, quality, and integrity of aquatic species and habitat.

State of the Ecosystem

Background

A significant portion of precipitation over the inland areas of the Great Lakes basin returns to the atmosphere by evapotranspiration. Water that does not return to the atmosphere either flows across the ground surface or infiltrates into the subsurface and recharges groundwater. 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. 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.

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. 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. In the Great Lakes region, groundwater discharge is often the dominant component of base flow. Base flow is the less variable and more persistent component of total stream flow.

Natural groundwater discharge is not the only component of base flow however, as various human and natural factors also contribute to the base flow of a stream. Flow regulation, the storage and delayed release of water using dams and reservoirs, creates a steady stream flow signature that is similar to that of groundwater discharge. Lakes and wetlands also moderate stream flow, transforming rapidly varying surface runoff into more slowly varying flow that approximates the dynamics of groundwater discharge. It is important to note that these varying sources of base flow affect surface water quality, particularly with regard to temperature.

Status of Base Flow

Base flow is frequently determined using a mathematical process known as hydrograph separation. This process uses stream flow monitoring information as input and partitions the observed flow into rapidly and slowly varying components, i.e., surface runoff and base flow, respectively. The stream flow data that are used in these analyses are collected across the Great Lakes basin using networks of stream flow gauges that are operated by the United States Geological Survey (USGS) and Environment Canada. Neff *et al*. (2005) summarize the calculation and interpretation of base flow for 3,936 gauges in Ontario and the Great Lakes states using six methods of hydrograph separation and length-of-record stream flow monitoring information for the periods ending on December 31, 2000 and September 30, 2001, respectively. The results reported by Neff *et al*. (2005) are the basis for the majority of this report.

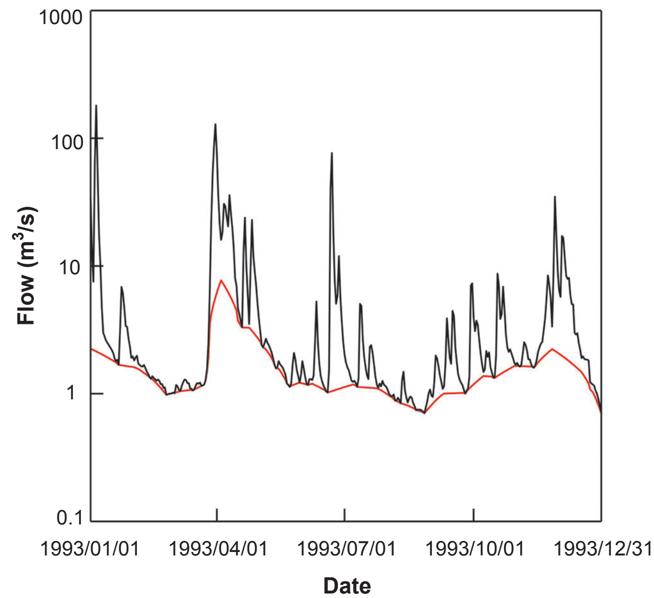

Figure 1. Hydrograph of observed total stream flow (black) and calculated base flow (red) for the Nith River at New Hamburg during 1993.
Source: Environment Canada and the U.S. Geological Survey.

Results corresponding to the United Kingdom Institute of Hydrology (UKIH) method of hydrograph separation (Piggott *et al*. 2005) are referenced throughout this report in order to maintain consistency with the previous report for this indicator. However, results calculated using the five other methods are considered to be equally probable outcomes.

Figure 1 illustrates the daily stream flow monitoring information and the results of hydrograph separation for the Nith River at New Hamburg, Ontario, for January 1 to December 31, 1993. The rapidly varying response of stream flow to precipitation and snow melt are in contrast to the more slowly varying base flow.

Application of hydrograph separation to daily stream flow monitoring information results in lengthy time series of output. Various measures are used to summarize this output. For example, base flow index is a simple, physical measure of the contribution of base flow to stream flow that is appropriate for use in regional scale studies. Base flow index is defined as the average rate of base flow relative to the average rate of total stream flow, is unitless, and varies from zero to one where increasing values indicate an increasing contribution of base flow to stream flow. The value of base flow index for the data shown in Figure 1 is 0.28, which implies that 28% of the observed flow is estimated to be base flow.

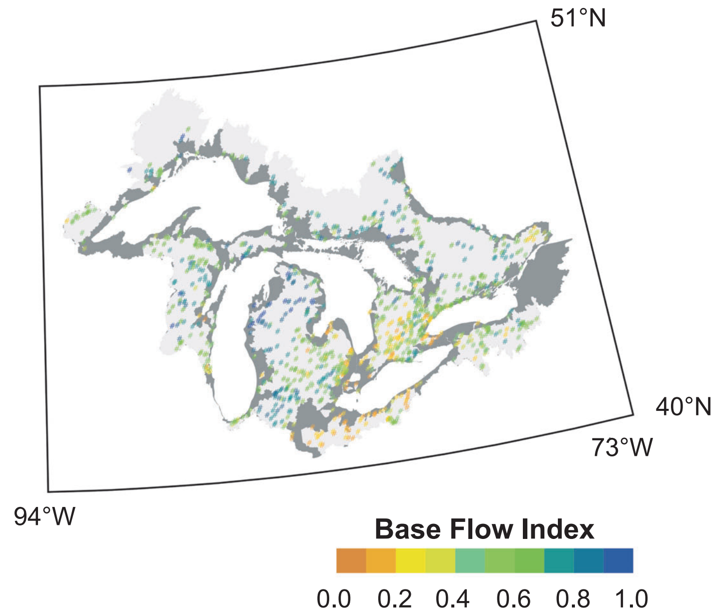

Figure 2. Distribution of the calculated values of base flow index relative to the gauged (light grey) and ungauged (dark grey) portions of the Great Lakes basin.
Source: Environment Canada and the U.S. Geological Survey.

Neff *et al*. (2005) used a selection of 960 gauges in Ontario and the Great Lakes states to interpret base flow. Figure 2 indicates the distribution of the values of base flow index calculated for the selection of gauges relative to the gauged and ungauged portions of the Great Lakes basin.

The variability of base flow within the basin is apparent. However, further processing of the information is required to differentiate the component of base flow that is due to groundwater discharge and the component that is due to delayed flow through lakes and wetlands upstream of the gauges.

An approach to the differentiation of base flow calculated using hydrograph separation into these two components is summarized in the following paragraphs of this report.

Variations in the density of the stream flow gauges and discontinuities in the coverage of monitoring are also apparent in Figure 2 and may have significant implications relative to the interpretation of base flow.

The values of base flow index calculated for the selection of gauges using hydrograph separation are plotted relative to the extents of surface water upstream of each of the gauges in Figure 3. The extents of surface water are defined as the area of lakes and wetlands upstream of the gauges relative to the total area upstream of the gauges. While there is considerable scatter among the values, the expected tendency for larger values of base flow index to be associated with larger extents of surface water is confirmed.

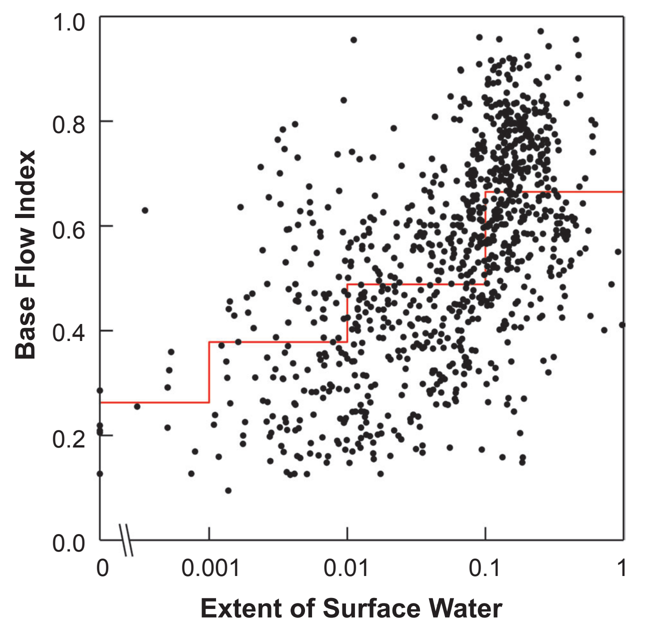

Figure 3. Comparison of the calculated values of base flow index to the corresponding extents of surface water.
The step plot (red) indicates the averages of the values of base flow index within the four intervals of the extent of surface water.
Source: Environment Canada and the U.S. Geological Survey.

Neff *et al*. (2005) modeled base flow index as a function of surficial geology and the spatial extent of surface water. Surficial geology is assumed to be responsible for differences in groundwater discharge and is classified into coarse and fine textured sediments, till, shallow bedrock, and organic deposits.

The modeling process estimates a value of base flow index for each of the geological classifications, calculates the weighted averages of these values for each of the gauges based on the extents of the classifications upstream of the gauges, and then modifies the weighted averages as a function of the extent of surface water upstream of the gauges.

A non-linear regression algorithm was used to determine the values of base flow index for the geological classifications and the parameter in the surface water modifier that correspond to the best match between the values of base flow index calculated using hydrograph separation and the values predicted using the model. The process was repeated for each of the six methods of hydrograph separation.

Extrapolation of base flow index from gauged to ungauged watersheds was performed using the results of the modeling process. The ungauged watersheds consist of 67 tertiary watersheds in Ontario and 102 eight-digit hydrologic unit code (HUC) watersheds in the Great Lakes states. The

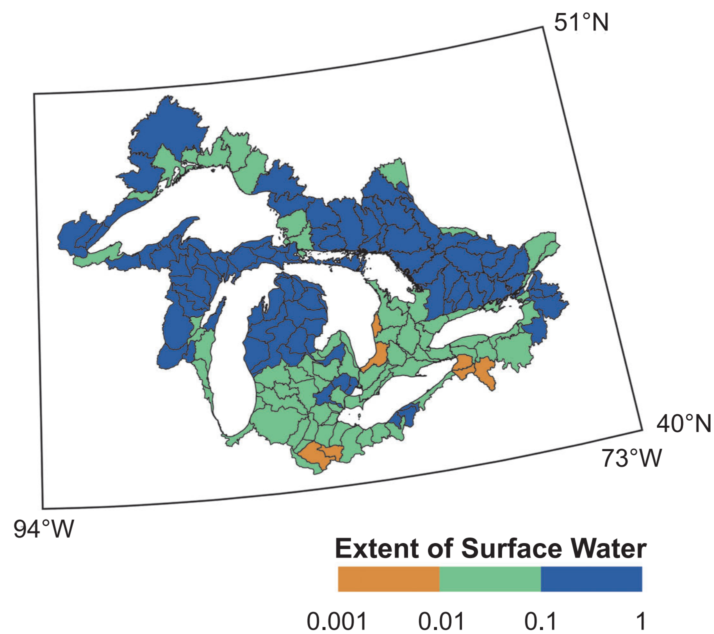

Figure 4. Distribution of the extents of surface water for the ungauged watersheds.
Source: Environment Canada and the U.S. Geological Survey.

extents of surface water for the ungauged watersheds are shown in Figure 4 where the ranges of values used in the legend match those used to average the values of base flow index shown in Figure 3.

A component of base flow due to delayed flow through lakes and wetlands appears to be likely over extensive portions of the Great Lakes basin.

The distribution of the classifications of geology is shown in Figure 5. Organic and fine textured sediments are not differentiated in this rendering of the classifications because both classifications have estimated values of base flow index due to groundwater discharge in the range of 0.0 to 0.1. However, organic deposits are of very limited extent and represent, on average, less than 2% of the area of the ungauged watersheds.

The spatial variation of base flow index shown in Figure 5 resembles the variation shown in Figure 2. However, it is important to note that the information shown in Figure 2 includes the influence of delayed flow through lakes and wetlands upstream of the gauges while this influence has been removed, or at least reduced, in the information shown in Figure 5.

Figure 6 indicates the values of the geological component of base flow index for the ungauged watersheds obtained by calculating the weighted averages of the values for the geological classifications that occur in the watersheds. This map therefore represents an estimate of the length-of-record contribution of base flow due to groundwater discharge to total stream flow that is consistent and seamless across the Great Lakes basin.

The pie charts indicate the range of values of the geological component of base flow index for the six methods of hydrograph separation averaged over the sub-basins of the Great Lakes. Averaging the six values for each of the sub-basins yields contributions of base flow due to groundwater discharge of approximately 60% for Lakes Huron, Michigan, and Superior and 50% for Lakes Erie and Ontario. There is frequently greater variability of this contribution within the sub-basins than among the sub-basins as the result of variability of geology that is more uniformly averaged at the scale of the sub-basins.

Mapping the geological component of base flow index, which is assumed to be due to groundwater

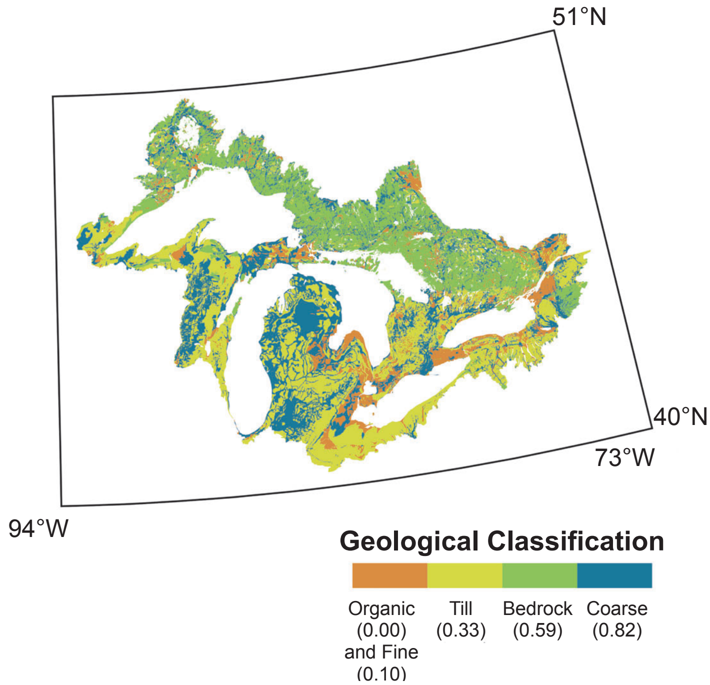

Figure 5. Distribution of the geological classifications.
The classifications are shaded using the estimated values of the geological component of base flow index shown in parentheses.
Source: Environment Canada and the U.S. Geological Survey.

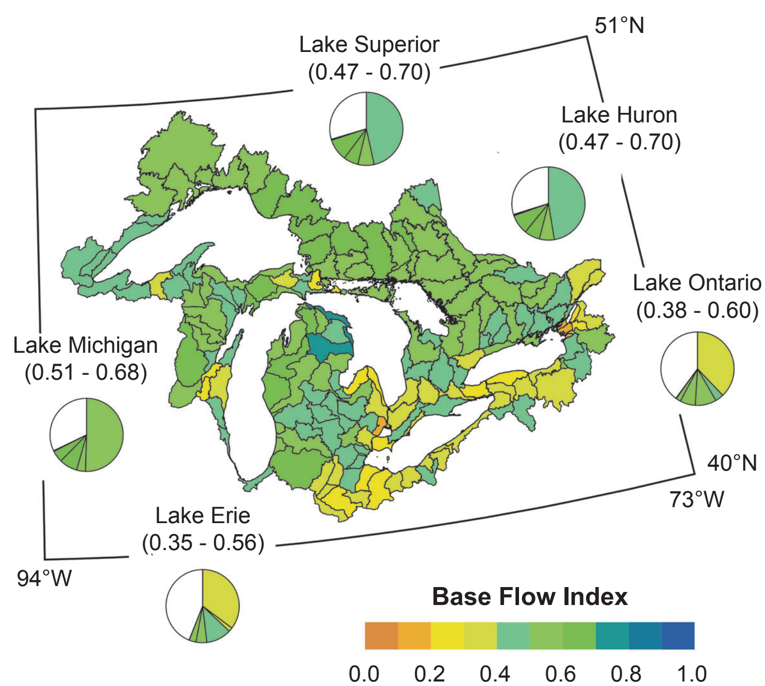

Figure 6. Distribution of the estimated values of the geological component of base flow index for the ungauged watersheds.
The pie charts indicate the estimated values of the geological component of base flow index for the Great Lakes sub-basins corresponding to the six methods of hydrograph separation. The charts are shaded using the six values of base flow index and the numbers in parentheses are the range of the values.
Source: Environment Canada and the U.S. Geological Survey.

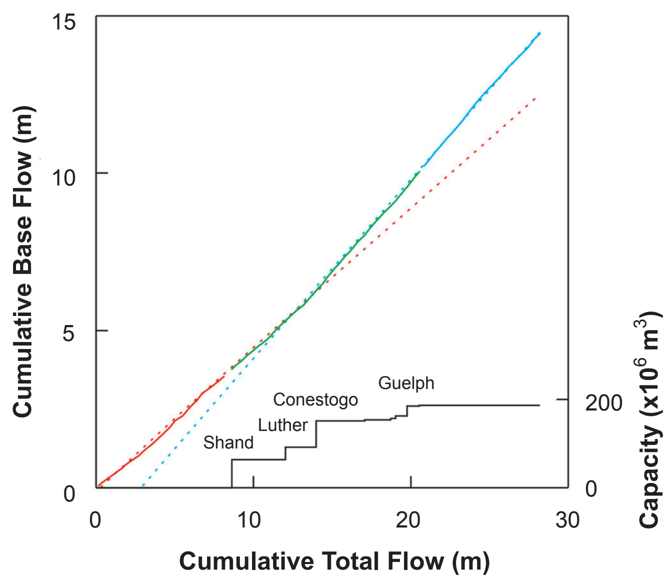

Figure 7. Cumulative base flow as a function of cumulative total flow for the Grand River at Galt prior to (red), during (green), and following (blue) the construction of the reservoirs that are located upstream of the stream flow gauge. The step plot indicates the cumulative storage capacity of the reservoirs where the construction of the largest four reservoirs is labeled. The dashed red and blue lines indicate uniform accumulation of flow based on data prior to and following, respectively, the construction of the reservoirs.
Source: Environment Canada and the U.S. Geological Survey.

discharge, across the Great Lakes basin in a consistent and seamless manner is an important accomplishment in the development of this indicator.

Additional information is, however, required to determine the extent to which human activities have impaired groundwater discharge. There are various alternatives for the generation of this information. For example, the values of base flow index calculated for the selection of stream flow gauges using hydrograph separation can be compared to the corresponding modeled values. If a calculated value is less than a modeled value, and if the difference is not related to the limitations of the modeling process, then base flow is less than expected based on physiographic factors and it is possible that discharge has been impacted by human activities. Similarly, if a calculated value is greater than a modeled value, then it is possible that the increased base flow is the result of human activities such as flow regulation and wastewater discharge. Time series of base flow can also be used to assess these impacts. The previous report for this indicator illustrated the detection of temporal change in base flow using data for watersheds with approximately natural stream flow and with extensive flow regulation and urbanization. However, no attempt has yet been made to systematically assess change at the scale of the Great Lakes basin.

Change in base flow over time may be subtle and difficult to quantify (e.g., variations in the relation of base flow to climate) and may be continuous (e.g., a uniform increase in base flow due to aging water supply infrastructure and increasing conveyance losses) or discrete (e.g., an abrupt reduction in base flow due to a new consumptive water use). Change may also be the result of cumulative impacts due to a range of historical and ongoing human activities, and may be more pronounced and readily detected at local scales than at the scales that are typical of continuous stream flow monitoring.

A local-scale approach to illustrating the impact of flow regulation on base flow is shown in Figure 7, with data for the Grand River at Galt, Ontario. The cumulative depth of base flow calculated annually as the total volume of flow at the location of the gauge during each year divided by the area that is upstream of the gauge, is plotted relative to cumulative total flow. The base flow index is the slope of the accumulation of base flow relative to the accumulation of total flow shown in Figure 7. The change in slope and increase in base flow index from a value of 0.45 prior to the construction of the reservoirs that are located upstream of the gauge to 0.57 following the construction of the reservoirs clearly indicates the impact of active flow regulation to mitigate low and high flow conditions. Calculating and interpreting

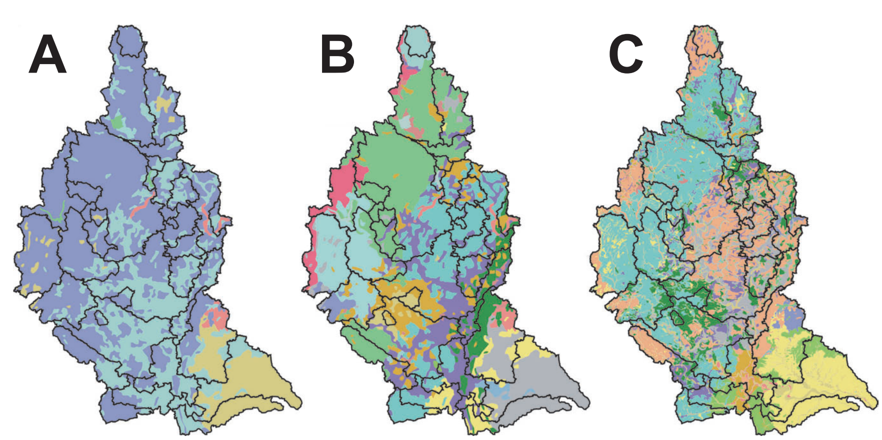

Figure 8. Geology of the gauged portion of the Grand River watershed based on the classification (A) and full resolution (B) of the 1:1,000,000 scale Quaternary geology mapping and the full resolution of the 1:50,000 scale Quaternary geology mapping (C) where random colors are used to differentiate the various geological classifications and units.
Source: Environment Canada and the U.S. Geological Survey.

diagnostic plots such as Figure 7 for hundreds to thousands of stream flow gauges in the Great Lakes basin will be a large and time consuming, but perhaps ultimately necessary, task.

Improving the spatial resolution of the current estimates of base flow due to groundwater discharge would be beneficial in some settings. For example, localized groundwater discharge has important implications in terms of aquatic habitat and it is unlikely that this discharge can be predicted using the current regional estimates of base flow.

The extrapolation of base flow information from gauged to ungauged watersheds described by Neff *et al*. (2005) is based on a classification and therefore reduced resolution representation of the Quaternary geology of the basin. Figure 8 compares this classification to the full resolution of the available 1:1,000,000 scale (Ontario Geological Survey (OGS) 1997) and 1:50,000 scale (OGS 2003) mapping of the geology of the gauged portion of the Grand River watershed in southern Ontario. Interpretation of base flow in terms of these more detailed descriptions of geology, where feasible relative to the network of stream flow gauges, may result in an improved estimate of the spatial distribution of groundwater discharge for input into functions such as aquatic habitat management.

Estimation of base flow using low flow observations, single "spot" measurements of stream flow under assumed base flow conditions, is another means of improving the spatial resolution of the current prediction of groundwater discharge. Figure 9 illustrates a series of low flow observations performed within the watershed of Duffins Creek above Pickering, Ontario, where the observations are standardized using continuous monitoring information and the drainage areas for the observations following the procedure described by Gebert *et al*. (2005) and then classified into 3-quantile groupings of high, intermediate, and low values.

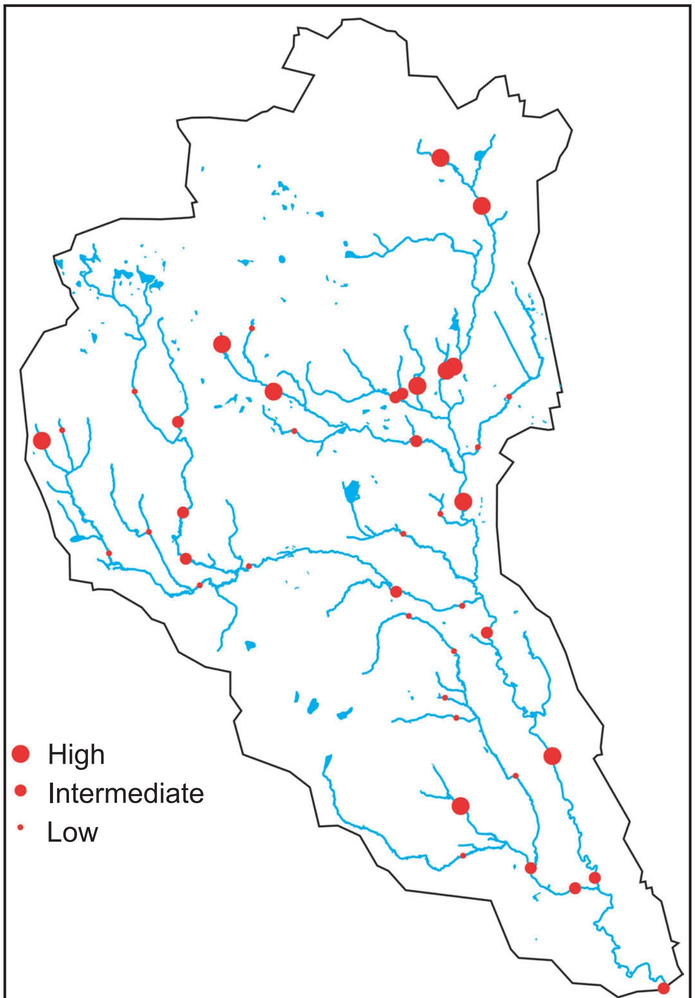

Figure 9. Distribution of the standardized values of low flow within the watershed of Duffins Creek above Pickering.
Source: Environment Canada and the U.S. Geological Survey, Geological Survey of Canada, and Ontario Ministry of Natural Resources.

The standardized values of low flow illustrate the spatially variable pattern of groundwater discharge that results from the interaction between surficial geology, the complex three-dimensional hydrostratigraphy, topography, and surface water features. Areas of potentially high groundwater discharge may have particularly important implications in terms of aquatic habitat for cold water fish species such as brook trout.

Finally, reconciling estimates of base flow generated using differing methods of hydrograph separation, perhaps by interpreting the information in a relative rather than absolute manner, will improve the certainty and therefore performance of base flow as an indicator of groundwater discharge. It may also be possible to assess the source of this uncertainty using chemical and isotopic data in combination with the methods of hydrograph separation if adequate data are available at the scale of the gauged watersheds. Figure 10 compares the values of base flow index calculated for the selection of 960 stream flow gauges in Ontario and the Great Lake states using the PART (Rutledge 1998) and UKIH methods of hydrograph separation. The majority of the values calculated using the PART method are greater than the values calculated using the UKIH method and there is considerable scatter in the differences among the two methods. The average of the differences between the two sets of values is 0.15 and is significant when measured relative to the differences in the estimates of base flow index for the sub-basins of the Great Lakes, which is on the order of 0.1.

Pressures

The discharge of groundwater to surface water features is the end-point of the process of groundwater recharge, flow, and discharge. Human activities impact groundwater discharge by modifying the components of this process where the time, scale, and to some extent the severity, of these impacts is a function of hydrogeological factors and the proximity of surface water features. Increasing the extent of impervious surfaces during residential and commercial development and installation of drainage to increase agricultural productivity are examples of activities that may reduce groundwater recharge and ultimately groundwater discharge.

Withdrawals of groundwater as a water supply and during dewatering (pumping groundwater to lower the water table during construction, mining, etc.) remove groundwater from the flow regime and may also reduce groundwater discharge. Groundwater discharge may be impacted by activities such as the channelization of water courses that restrict the motion of groundwater across the groundwater and surface water interface. Human activities also have the capacity to intentionally, or unintentionally, increase groundwater discharge. Induced storm water infiltration, conveyance losses within municipal water and wastewater systems, and closure of local water supplies derived from groundwater are examples of factors that may increase groundwater discharge. Climate variability and change may compound the implications of human activities relative to groundwater recharge, flow, and discharge.

Management Implications

Groundwater has important societal and ecological functions across the Great Lakes basin. Groundwater is typically a high quality water supply that is used by a significant portion of the population, particularly in rural areas where it is often the only available source of water. Groundwater discharge to rivers, lakes, and wetlands is also critical to aquatic species and habitat and to in-stream water quantity and quality. These functions are concurrent and occasionally conflicting.

Pressures such as urban development and water use, in combination with the potential for climate impacts and further contamination of the resource, may increase the frequency and severity of these conflicts. In the absence of systematic accounting of groundwater supplies, use, and dependencies, it is the ecological function of groundwater that is most likely to be compromised.

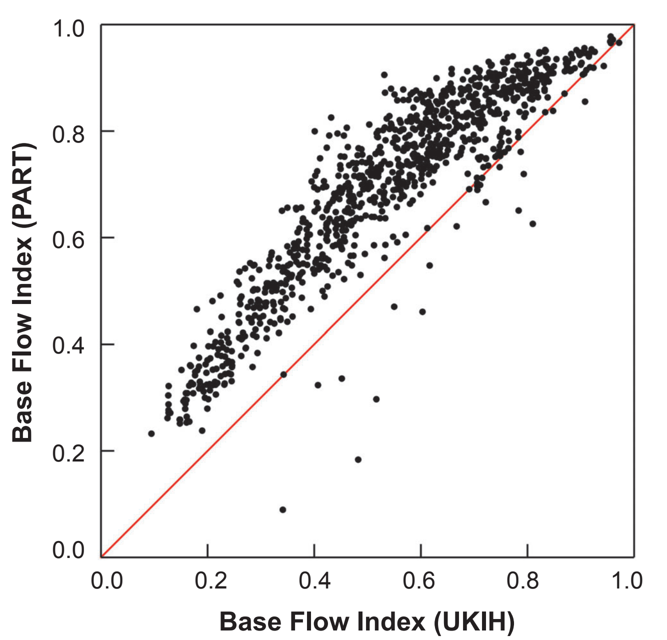

Figure 10. Comparison of the values of base flow index calculated using the PART method of hydrograph separation to the values calculated using the UKIH method.
Source: Environment Canada and the U.S. Geological Survey.

Managing the water quality of the Great Lakes requires an understanding of water quantity and quality within the inland portion of the basin, and this understanding requires recognition of the relative contributions of surface runoff and groundwater discharge to stream flow. The results described in this report indicate the significant contribution of groundwater discharge to flow within the tributaries of the Great Lakes. The extent of this contribution has tangible management implications. There is considerable variability in groundwater recharge, flow, and discharge that must be reflected in the land and water management practices that are applied across the basin.

The dynamics of groundwater flow and transport are different than those of surface water flow. Groundwater discharge responds more slowly to climate and maintains stream flow during periods of reduced water availability, but this capacity is known to be both variable and finite. Contaminants that are transported by groundwater may be in contact with geologic materials for years, decades, and perhaps even centuries or millennia. As a result, there may be considerable opportunity for attenuation of contamination prior to discharge. However, the lengthy residence times of groundwater flow also limit opportunities for the removal of contaminants, in general, and non-point source contaminants, in particular.

Comments from the author(s)

The indicated status and trend are estimates that the authors consider to be a broadly held opinion of water resource specialists within the Great Lakes basin. Further research and analysis is required to confirm these estimates and to determine conditions on a lake by lake basis.

Base flow information cited in the report is a product of the study, *Groundwater and the Great Lakes: A Coordinated Binational Basin-wide Assessment in Support of Annex 2001 Decision Making*, conducted by the U.S. Geological Survey in cooperation with Environment Canada's National Water Research Institute and the Great Lakes Protection Fund. Data are published in Neff *et al*. (2005), cited below.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			
Clarifying Notes:						

Acknowledgments

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Marc Hinton, Geological Survey of Canada.
Contributors: Lori Fuller, U.S. Geological Survey
Jim Nicholas, U.S. Geological Survey.

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Last Updated
State of the Great Lakes 2009

Groundwater Dependent Plant and Animal Communities
Indicator #7103

Overall Assessment

Status: **Not Assessed**
Trend: **Not Assessed**
Rationale: **The identification of cold groundwater-fed headwater streams would provide useful information for the development of watershed management plans that seek to protect groundwater sources, and the integrity of the downstream cold water ecosystems.**

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 are 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.

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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 and 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 (Fig. 1). These surficial overburden deposits are underlain by thick sequences of fractured carbonate rock (predominantly dolostone).

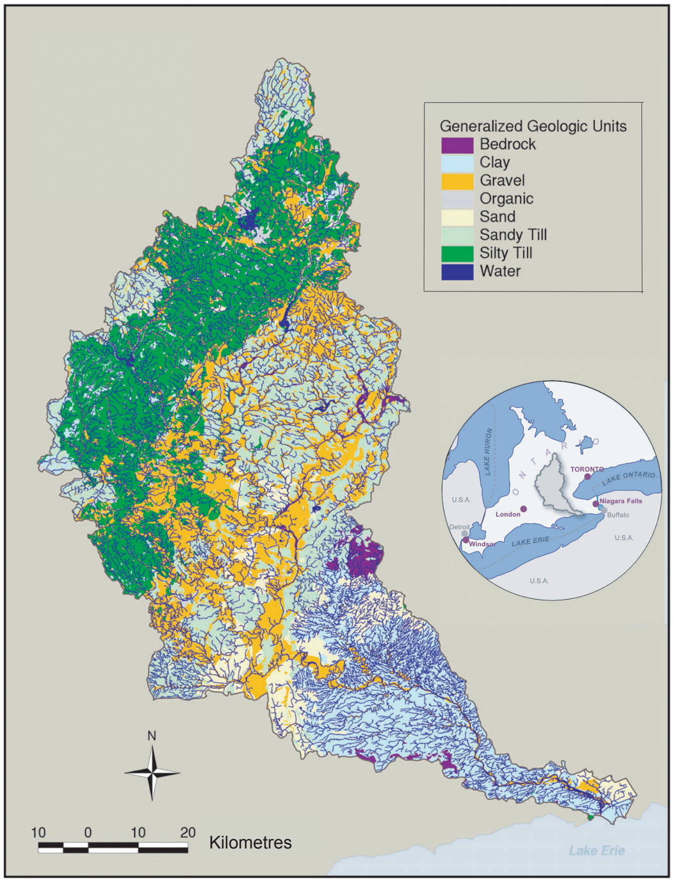

Figure 1. Surficial geology of the Grand River watershed.
Source: Grand River Conservation Authority.

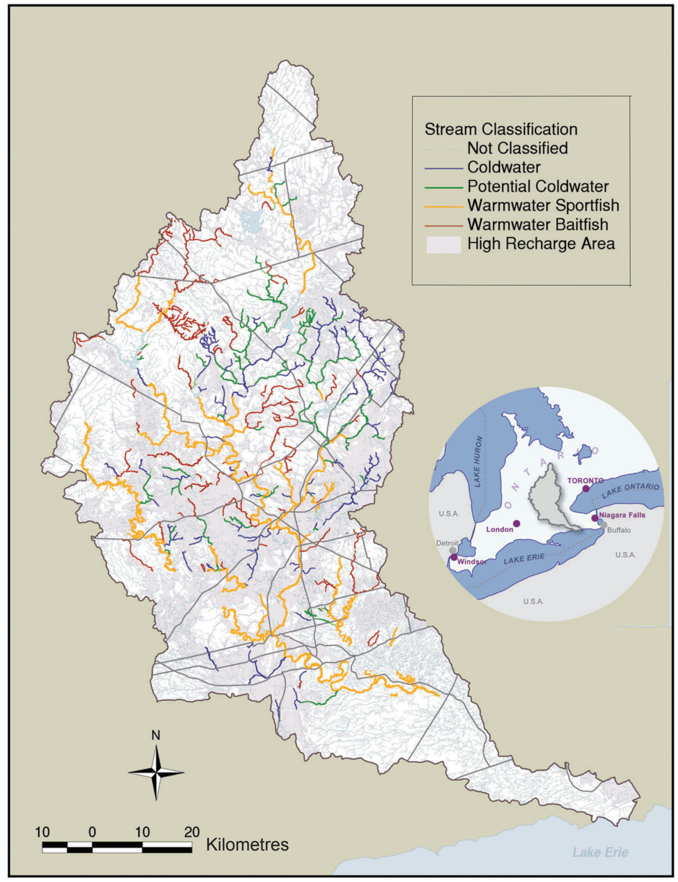

Figure 2. Streams of the Grand River watershed.
Source: Grand River Conservation Authority.

The Grand River and its tributaries form a stream network housing approximately 11,329 km (7,040 miles) 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 OMNR database currently available through the Natural Resources and Values Information System (NRVIS) has documented and classified about 22% of the watershed's streams (Fig. 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.

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 (Fig. 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 favorable to groundwater discharge. Brook trout is a freshwater fish species native to Eastern Canada. The survival and success of brook trout are 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.

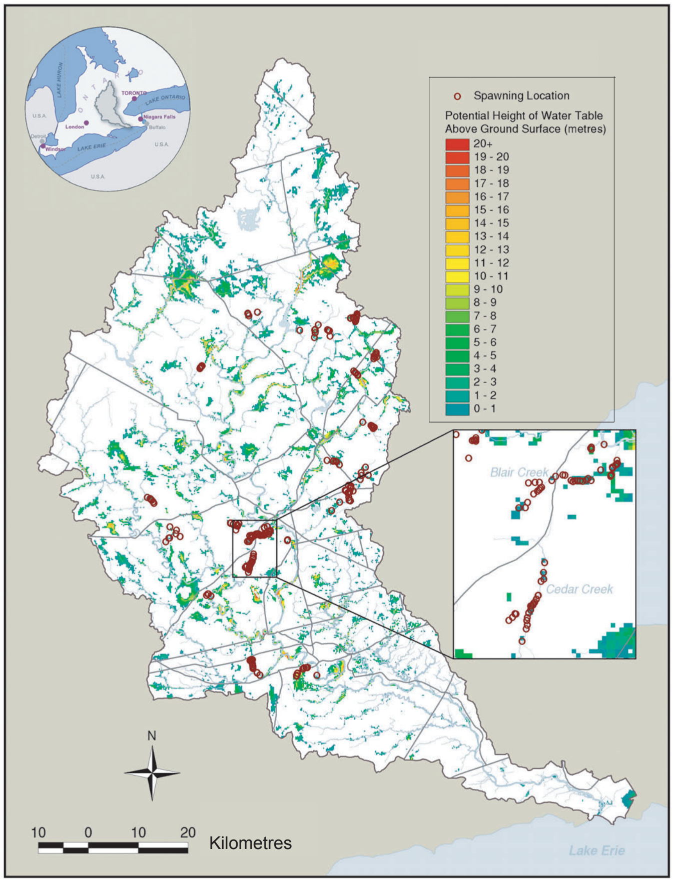

Figure 3. Map of potential discharge areas in the Grand River watershed.
Source: Grand River Conservation Authority.

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. Salmonid spawning surveys for brook trout were carried out over similar stretches of the creek in 1989 and 2003 (Fig. 4). In 1989, a total redd count of 53 (over 4.2 km (2.6 miles)) was surveyed while in 2003 the total redd count was 59 (over 5.4 km (3.4 miles)). 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 (20.3 redds/mile) and 10.9 redds/km (17.5 redds/mile) 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.

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.

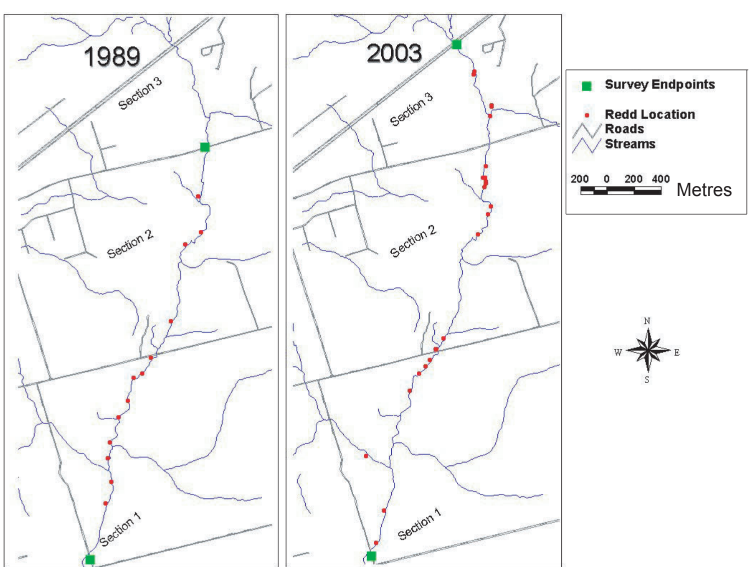

Figure 4. Results of brook trout spawning surveys carried out in the Cedar Creek subwatershed in 1989 and 2003.
Source: Grand River Conservation Authority.

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.

Comments from the author(s)

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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
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5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments

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Last Updated
State of the Great Lakes 2009

Area, Quality and Protection of Special Lakeshore Communities - Alvars

Indicator #8129 (Alvars)

This indicator report was last updated in 2000.

Overall Assessment

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

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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
- 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 (United States and Canada 1987).

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 (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 kilometer of the shore.

	Total in Basin	Nearshore
No. of alvar sites	82	52
No. of community occurrences	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.

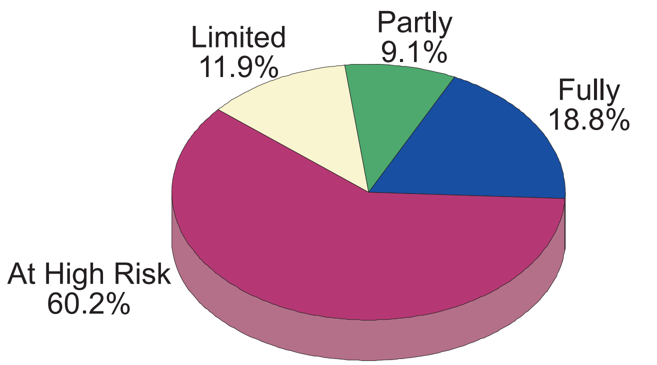

Figure 1. Protection status of nearshore alvar area (2000).
Source: Ron Reid, Bobolink Enterprises.

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 are at high risk. 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 (Fig. 2). Other states have too few nearshore sites to allow comparison.

Each location of an alvar community or rare species has been documented as an "element occurrence" or EO. Each alvar 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.

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 (5,289.5 acres) of alvars across the Great Lakes basin, with 1353.5 ha (3,344.6 acres) of that within the nearshore area. Most of the secured nearshore area is through land acquisition, but 22.7 ha (56.1 acres) on Pelee Island (ON) are through a conservation easement, and 0.6 ha (1.5 acres) 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 (*Rhamnus cathartica*) and dog-strangling vine(*Cynanchum louiseae* and *Cynanchum rossicum*).

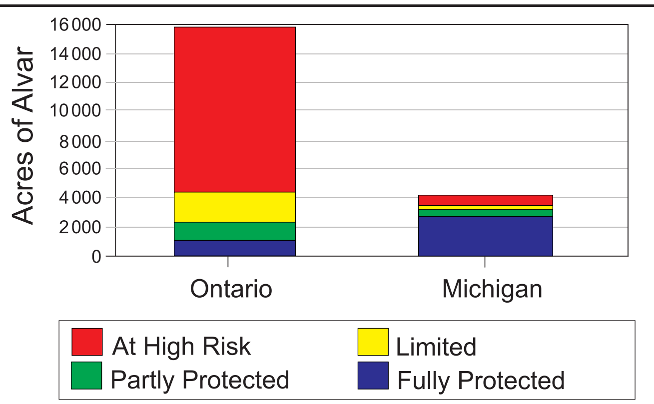

Figure 2. Comparison of the protection status of nearshore alvars (in acres) for Ontario and Michigan.
Source: Ron Reid, Bobolink Enterprises.

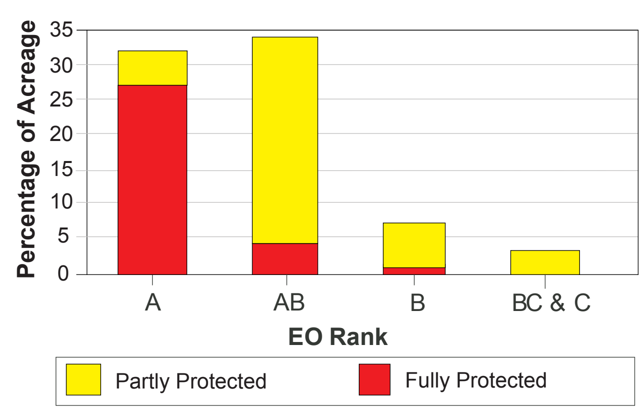

Figure 3. Protection of high quality alvars.
EO Rank = Element Occurrence (A is excellent, B is good and C is marginal).
Source: Ron Reid, Bobolink Enterprises.

Comments from the author(s)
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 6,880 ha (17,000 acres) through a cooperative project of The Nature Conservancy of Canada, The Nature Conservancy, Federation of Ontario Naturalists, and Ontario Ministry of Natural Resources.

Acknowledgments
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Heather Potter, The Nature Conservancy, Chicago, IL.

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Last Updated
State of the Great Lakes 2000
[Editor's note: A condensed version of this report was published in the State of the Great Lakes 2001.]

Area, Quality and Protection of Special Lakeshore Communities - Cobble Beaches

Indicator #8129 (Cobble Beaches)

This indicator report was last updated in 2005.

Overall Assessment

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

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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
- 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 (United States and Canada 1987).

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 United States 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.

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.

Lake Superior has the most cobble shoreline of all the Great Lakes with 958 km (595 miles) of cobble beaches (Fig. 1); 541 km (336 miles) in Canadian and 417 km (259 miles) in the United States side. This constitutes 20% of the whole Lake Superior shoreline (11.3% in Canadian and 8.7% in the United States).

Lake Huron has the 2nd most cobble shoreline with approximately 483 km (300 miles) of cobble shoreline; 330 km (205 miles) in Canadian and 153 km (95 miles) in the United States. Most of the cobble beaches are found along the shoreline of the Georgian Bay (Fig. 2). This constitutes approximately 9% of the whole Lake Huron shoreline (6.1% in Canadian and 2.8% in the United States).

Figure 2. Cobble beaches along Lake Huron's shoreline (red = cobble beach locations).
Source: Environment Canada.

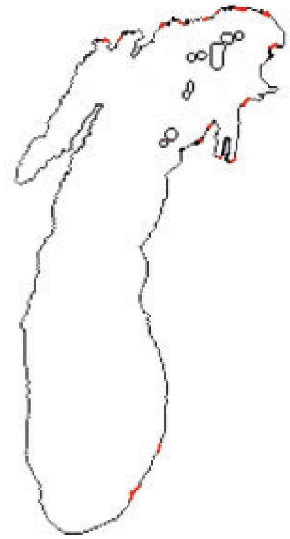

Figure 3. Cobble beaches along Lake Michigan's shoreline (red = cobble beach locations).
Source: Albert (1994a), Humphrys *et al.* (1958).

Approximately 164 km (102 miles) 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 (Fig. 3).

Lake Ontario has very little cobble shoreline of about 35 km (22 miles), representing only 3% of its shoreline (Fig. 4).

Lake Erie has the smallest amount of cobble shoreline of all the Great Lakes with only 26 km (16 miles) of cobble shore. This small area represents approximately 1.9% of the lake's shoreline (Fig. 5).

Figure 4. Cobble beaches along Lake Ontario's shoreline (red = cobble beach locations).
Source: International Joint Commission (IJC) and Christian J. Stewart.

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 (*Tanacetum huronense*) and redroot (*Lachnanthes caroliana*). It is also home to the endangered heart-leaved plantain (*Plantago cordata*), which is protected under the Ontario Endangered Species Act.

Lake Michigan and Lake Huron's cobble shorelines are home to Houghton's goldenrod (*Oligoneuron houghtonii*) and the dwarf lake iris (*Iris lacustris*), 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 sedge (*Tanacetum bipinnatum ssp. Huronense*) and beauty sedge (*Carex cocinna*) (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.

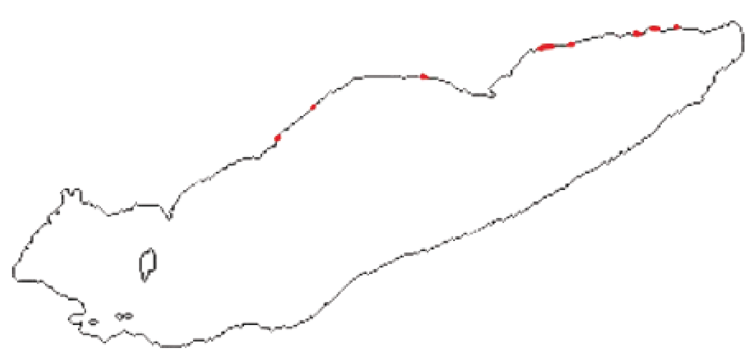

Figure 5. Cobble beaches along Lake Erie's shoreline (red = cobble beach locations).
Source: Environment Canada.

Pressures

Cobble beaches are most frequently threatened and lost by shoreline development. Homes built along the

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	
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.

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.

Comments from the author(s)

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 (IJC) 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.

Acknowledgments

Author: Jacqueline Adams, Environmental Careers Organization, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office.

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Last Updated
State of the Great Lakes 2005

Area, Quality and Protection of Special Lakeshore Communities – Sand Dunes

Indicator #8129 (Sand Dunes)

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **Inadequate data exist to determine overall status and trend at this time. Comprehensive dune mapping needs are necessary.**
Note: This is a progress report towards implementing this indicator.

Lake-by-Lake Assessment

Lake Superior
Status: Not Assessed
Trend: Undetermined

Lake Michigan
Status: Good
Trend: Deteriorating
Rationale: Dune habitat is being impacted by both biological and anthropogenic forces. Invasive species have spread, destabilizing the system, and increasing human development footprints divide, impact and damage the both the connectedness and quality of the dynamic Lake Michigan dune ecosystem.

Lake Huron
Status: Not Assessed
Trend: Undetermined

Lake Erie
Status: Mixed
Trend: Improving
Rationale: Currently no formal study of dunes on Presque Isle is underway. There has been ongoing informal management and monitoring the past 8–10 years. Local and regional experts provide input into management strategies. Improvements are made as time and resources allow.

Lake Ontario
Status: Mixed
Trend: Improving
Rationale: United States dune management has been in place for 30 years, with strict regulatory structure. Canada is bringing natural resource needs into dune management. United States has 27.4 km (17 miles) of dunes (19.9 km (10.5 mi) private and 10.5 km (6.5 public)). Canada has a few natural dunes in protected areas.

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 area, extent and quality of Great Lakes sand dunes, ensuring adequate representation of sand dune types across their historical range.

State of the Ecosystem
A working definition for "sand dunes" was developed for this report as hills, mounds or ridges of wind deposited sand with a variety of plant communities. Great Lakes sand dunes can be divided into four distinct and general zones, which are based upon these plant communities: beach, foredune, trough/swale or interdunal pond, and backdune forest.

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 and house globally significant shorebird habitats. Sand dunes can be found along the coasts of all the Great Lakes. The states bordering Lake Michigan, however, have the greatest number of sand dunes with a total of 111,291 hectares (275,006 acres), followed by the Province of Ontario (Canada) with 8,910 hectares (22,017 acres). Of the individual states, Indiana has 6,070 hectares (14,999 acres), New York has 4,850 hectares (11,984 acres), and Wisconsin has 425 hectares (1,050 acres) (2005); the area of dunes in Illinois and Michigan are not known. This information is not complete. No comprehensive map of Great Lakes sand dunes exists.

Degree of protection varies considerably among jurisdictions making it difficult to assess the overall loss or status of the Great Lakes sand dunes. Although information about the quality of individual sand dunes is often 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 Dune 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 overall. 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. The Lake Ontario sand dunes are threatened by sand starvation. In New York (Lake Ontario) sand loss into sheltered ponds and wetlands has been progressive over the last 100 years. Some of this has been due to erosion accelerated by inappropriate use, but recently inlet dynamics has been shown to be a significant cause.

Management Implications
Many actions have been taken to protect Great Lakes sand dunes. For example, in Eastern Lake Ontario in the United States 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. The United States side of Eastern Lake Ontario has developed an educational based stewardship program (20+ years) as a result of the [Lake] Ontario Dune Coalition. The Eastern Lake Ontario Dune Stewards patrol the public dune areas promoting environmentally sound use of the resource areas while collecting visitor usage data.

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.

Comments from the Author(s)
A group of sand dune managers, educators, private landowners, and scientists attended a conference in 2006 to exchange information and form a network for future information exchange on Great Lakes sand dune ecosystem ecology, management, research and education efforts. Attendees from six United States and the Province of Ontario Canada included 75 scientists, public and private land managers, and professional as well as volunteer educators. Attendees came from federal, state/provincial, county and local government agencies, non-profit conservation groups, and private landowner associations. National and State Parks were represented, regulatory and natural resource management agencies, cottage owners, soil and water conservation professionals,

interpretive center educators, and two state-level collaboratives for dune conservation and management. Fourteen speakers shared expertise on the areas of research, management and public education over the course of a conference. In addition, 27 attendees presented their work in posters on display throughout the conference. This group could work actively to collect available data about Great Lakes sand dunes and begin collaborative actions to protect them.

Since the Great Lakes Dune Conference the conference committee continued holding conference calls to develop the following products:

1. The pre-conference website has been converted to a post-conference website and now includes posters and PowerPoint presentations that have been made available by presenters (http://www.nysgdunes.org/confhomepage.htm).

2. A Listserv (gldunes) hosted by GLIN (Great Lakes Information Network) co-managed by Michigan Sea Grant and New York Sea Grant was created to address the need for communication both across disciplines and geographically.

3. A Great Lakes Dune session was held at the International Association for Great Lakes Research (IAGLR) at Penn State, PA in May-June 2007.

Functional relationships exist between coastal wetlands and freshwater sand dunes. It is difficult for sand dune managers, educators, private land owners, and scientists to exist in their functional capacity without interacting with the coastal wetlands. Not only can professional partnerships be built (across disciplines) with parties interested in sand dune issues, but also those interests in coastal wetlands.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization			X			
2. Data are traceable to original sources			X			
3. The source of the data is a known, reliable and respected generator of data			X			
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			
Clarifying Notes: In some cases data may be available and reliable locally, but not system-wide.						

Acknowledgments
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Last Updated
State of the Great Lakes 2009

Area, Quality and Protection of Special Lakeshore Communities - Islands

Extent, Condition and Conservation Management of Great Lakes Islands

Indicator #8129 (Islands)

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **This project established baseline information that will be used to assess future trends. Results reflect detailed analyses from Canadian islands and preliminary results from U.S. islands.**

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Undetermined
Rationale: Detailed analysis for Canada only. A preliminary analysis of Lake Superior islands in the United States is nearly complete.

Lake Michigan
Status: Mixed
Trend: Undetermined
Rationale: A preliminary analysis of Lake Michigan islands in the United States is nearly complete.

Lake Huron
Status: Mixed
Trend: Undetermined
Rationale: Detailed analysis for Canada only. A preliminary analysis of Lake Huron Islands in the United States is nearly complete.

Lake Erie
Status: Mixed
Trend: Undetermined
Rationale: Detailed analysis for Canada only. Preliminary analyses have been completed for Lake Erie islands in the United States.

Lake Ontario
Status: Mixed
Trend: Undetermined
Rationale: Detailed analysis for Canada only. Preliminary analyses have been completed for Lake Ontario islands in the United States.

Purpose

- To assess the status of Great Lakes islands, one of the 12 special lakeshore communities identified within the nearshore terrestrial area
- To assess changes in area and quality of Great Lakes islands individually, within lake units, and as an ecologically important system
- To assess amount and suitability of island habitat for focal species and communities in the Great Lakes ecosystem
- To infer success of management activities
- To focus future conservation efforts toward the most ecologically significant island habitats in the Great Lakes that face threats and are not adequately protected

Ecosystem Objective

The long-term objective is to ensure the conservation, protection, and preservation of the islands of the Great Lakes, including their unique landforms, plants, animals, cultural history, and globally important biological diversity.

State of the Ecosystem

Background

This project created the first binational database and detailed mapping of the islands[1] of the Great Lakes (Fig.1). This effort identified 31,407 island polygons[2] with a total coastline of 15,623 km (9,708 mi). The islands range in size from no bigger than a large boulder to the world's largest freshwater island, Manitoulin. They often form chains of islands known as archipelagos. Though this is not well known, the Great Lakes contain the world's largest freshwater island system, and the islands are globally significant in terms of their biological diversity. Despite this, the state of our knowledge about islands as a collection is very limited.

Due to their 360-degree exposure to coastal processes, islands are vulnerable and sensitive to change. They are exposed to forces of erosion and accretion as water levels rise and fall, and to weather events. Although very few subspecies, species, or communities are restricted to Great Lakes islands, some endemic (found exclusively in one ecoregion) or limited-range (found primarily in one ecoregion, but extending to one or two other ecoregions) species and communities occur disproportionately on islands. Because of their isolation, many offshore islands have assemblages of plants and animals that do not occur on the mainland as well as unique predator-prey relationships and low densities of herbivores.

Some Great Lakes islands represent the most remote wilderness areas in the Great Lakes ecoregion. These wilderness islands provide refuge for unique biological resources. Islands need to be considered a single irreplaceable resource and protected in their entirety 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, and their value is enhanced when islands are protected in the context of the whole. For example, in Ontario, over 320 provincially rare species, including 27 globally rare species, occur on islands. Soule (1999) reported that the state of Michigan's 600 Great Lakes islands contain one-eleventh 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, nearctic-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 in this Lake 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.

Methods

Table 1 provides a summary of the number of islands and island groups (complexes) within each coastal environment in Ontario, including the mean and range for the biodiversity and threat score. These scores provide a summary of relative biodiversity significance and relative threats for islands in each coastal environment. Islands and island complexes were assigned scores based on three categories: 1) biodiversity values, 2) potential threats, and 3) existing conservation progress. The criteria from Ewert *et al*. (2004) were modified and used as a basis to build an enhanced scoring method that could use an automatic approach to assess the biodiversity of islands. Biodiversity criteria used included biological diversity, physical diversity, size and distinctiveness. The analysis of threats considered direct potential threats such as boat launches, anchorages, residences, cottages, building density, invasive species, pits, quarries, and lighthouses. Indirect potential threats included distance to mining claims, road density, and percent of island occupied by cropland. Conservation progress was also assessed for each island and island complex by measuring the amount of protected areas. For Ontario islands parks, protected areas, conservation lands, and existing recognition of biodiversity values were assigned into four categories to reflect the general type of associated conservation. Protected areas on U.S. islands are currently being identified and assigned categories. Existing conservation progress scores did not directly contribute to biodiversity or threat scores, but the proportion of these conservation lands on each island and island complex were assessed to provide further insight into island values and identify potential conservation gaps and needs.

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1 We define island as any land mass, natural or artificial, within the Great Lakes and connecting channels that is surrounded by an aquatic environment.

2 Island polygons are based on remote mapping information and small islands in close proximity may be mapped as a single unit. As a result, 31,407 is a conservative estimate. Additionally, the shape and number of islands can change depending on water levels.

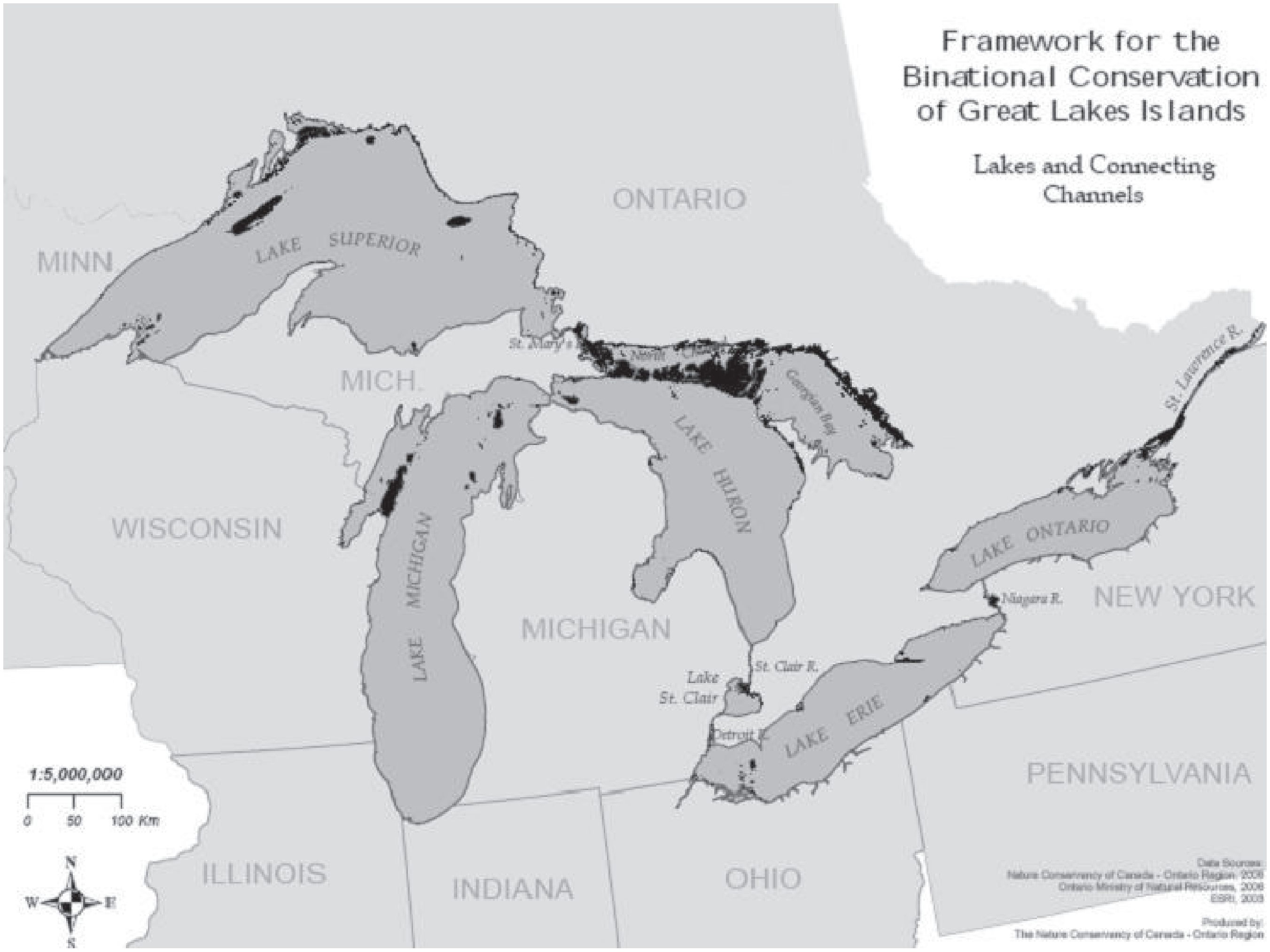

Figure 1. The first combined map of Canadian and United States islands of the Great Lakes.
Source: Vigmostad, K.E., F. Cuthbert, D. Ewert, D. Kraus, M. Seymour, and L. Wires. 2007. Great Lakes Islands: Biodiversity Elements and Threats. Final Report to the Great Lakes National Program Office of the Environmental Protection Agency.

Summary of Islands by Lake

Lake Superior

A total (Canada and United States.) of 2,591 island polygons were identified. St. Marys River has 630 island polygons. Canadian islands in Lake Superior have the lowest threats score in the basin. A high proportion of these islands are within protected areas and conservation lands. Overall condition is good. These islands include a high number of disjunct (separated geographically) plant species.

Lake Huron

A total (Canada and United States) of 23,719 island polygons (including Georgian Bay) were identified. Canadian islands tend to be more threatened in the south compared to the north. In the United States, many islands along Michigan's Lower Peninsula are partially or completely protected along with a number of islands off the Upper Peninsula. A large number of protected areas and conservation lands occur in the northern region. Southern regions are more developed and under increasing pressures from development and invasive species. These islands include a high number of globally rare species and vegetation communities.

Lake Michigan

A total (United States) of 329 island polygons were identified. Only preliminary analyses have been completed. Although many islands are quite isolated and have little or no threats, others are near the shore, have permanent human populations, and are threatened by several factors.

Lake Erie
A total (Canada and United States) of 1,724 island polygons were identified. Other nearby island polygons include those in Lake St. Clair and the St. Clair River (339), Detroit River (61), and Niagara River (36). These islands include a mix of protected areas and private islands. Islands in the western Lake Erie basin have some of the highest biodiversity values of all Great Lakes islands.

Lake Ontario
A total (Canada and United States) of 2,591 island polygons (including upper St. Lawrence River) were identified. Many of these islands have high threat index scores and long histories of recreational use (Table 1). One of the highest building point counts occurs for these islands. Few areas have been protected.

Coastal Environment *	No. Individual Islands	No. Islands/ Complexes	Biodiversity Score		Threat Score	
			Mean	Range	Mean	Range
Georgian Bay 1	3992	595	85.2	0-345	1.3	0-65
Georgian Bay 2	17615	848	90.2	0-290	11.8	0-52
Georgian Bay 3	38	22	93.9	57-244	8.2	1-46
Georgian Bay 4	36	18	95.8	47-195	5.7	1-33
Georgian Bay 5	290	90	103.6	39-300	4.0	1-44
Georgian Bay 6	225	119	92.8	46-401	9.7	1-581
Lake Erie 1	0	0	0	0	0	0
Lake Erie 2	15	15	151.7	87-388	11.2	1-88
Lake Erie 3	2	2	92.5	91-94	1.0	1
Lake Erie 4	66	13	198.9	154-340	4.8	1-32
Lake Erie 5	2	2	90.5	87-94	2.0	1-3
Lake Erie 6	1461	30	203.4	81-333	9.7	1-41
Lake Erie 7	21	18	88.4	57-143	7.7	1-42
Lake Erie 8	17	4	144.5	96-164	2.3	1-6
Lake Huron 1	887	173	103.4	39-490	8.2	1-179
Lake Huron 2	31	19	85.0	57-137	3.4	1-22
Lake Huron 3	8	5	127.0	114-145	2.8	1-4
Lake Ontario 1	0	0	0	0	0	0
Lake Ontario 2	9	7	108.6	90-148	2.3	1-5
Lake Ontario 3	34	13	127.0	86-190	7.0	1-27
Lake Ontario 4	74	32	131.5	83-231	3.3	1-22
Lake Ontario 5	603	171	114.1	44-302	3.7	1-143
Lake Superior 1	167	117	84.6	39-290	2.2	1-25
Lake Superior 2	1228	459	81.2	37-288	2.0	1-40
Lake Superior 3	495	160	71.7	40-195	2.4	1-28
Lake Superior 4	77	28	97.2	57-253	3.3	1-26
Lake Superior 5	246	45	93.6	49-275	8.8	1-138
St. Clair 1	21	11	119.7	84-187	22.1	1-46
St. Clair 2	234	25	162.2	92-336	9.2	1-68
St. Clair 3	53	11	160.3	102-239	6.0	1-36
St. Clair 4	1	1	116	116	2	2
St. Clair 5	41	14	162.1	79-231	11.5	1-36
St. Lawrence 1	337	111	92.4	44-211	19.5	1-81

Table 1. Biodiversity and Threat Scores for Great Lakes Islands (Canada only), by coastal environment.
* Islands were grouped according to their Great Lakes coastal environment (Owens 1979). Coastal environments are based on relief, geology, fetch, wave exposure, ice conditions, and availability and transport of sediment. This report splits some larger islands (e.g., Manitoulin) into different zones to reflect distinctive coastal characteristics. The Great Lakes shoreline on the Canadian side was divided into 33 coastal environments. A similar method will be used to designate coastal environments for the U.S. islands.
Source: Nature Conservancy of Canada, Ontario Region.

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 sufficient scientific information about sustainable use to evaluate, prioritize, and make appropriate natural resource decisions on islands. Island stressors include habitat loss and fragmentation, invasive species, toxic substances, overharvest, and global climate change.

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. The *Framework for Binational Conservation of Great Lakes Islands* will be completed in 2009. In addition, based on a threat assessment, the Collaborative will recommend management strategies to reduce the pressures on a set of Priority Island Conservation Areas (PICAs)—those island areas with high biodiversity values that face threats and are not yet adequately protected and thus will be the focus of conservation efforts.

Comments from the authors
The Great Lakes islands provide a unique opportunity to protect a resource of global importance because many islands still remain intact. The first gathering of Great Lakes island experts was in 1996 and led to publication of the first evaluation of island conservation value (Vigmostad 1999). The U.S. Fish and Wildlife Service's Great Lakes Basin Ecosystem Team (GLBET)

provided leadership to coordinate and improve the protection and management of the islands of the Great Lakes. The GLBET island initiative includes the coordination and compilation of island geospatial data and information, developing standardized survey/monitoring protocols, holding an island workshop in the fall of 2002 to incorporate input from partners for addressing the Great Lakes Island indicator needs, and completion of a Great Lakes Island Conservation Strategic Plan.

A subset of the GLBET formed the binational Collaborative for the Conservation of Great Lakes Islands. Recently, the Collaborative received a habitat grant from the U.S. 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 developed:

- An island biodiversity assessment and ranking system (based on a subset of biodiversity parameters) that will provide a foundation to prioritize island conservation
- A freshwater island classification system
- 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 proposed 10 state, five pressure, and two response indicators. The suite of island indicators is still being evaluated, but will be reported on in future years. 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. The Collaborative is currently drafting the *Framework for the Binational Conservation of Great Lakes Islands*, which is expected to be released in 2009.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Sources

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Additional Resources

U.S. Fish and Wildlife Service's Great Lakes Basin Ecosystem Team island website: http://www.fws.gov/midwest/greatlakes/gli.htm

Future Great Lakes Islands Collaborative website (in early stages of development): www.greatlakesislands.org

Last Updated

State of the Great Lakes 2009

Extent of Hardened Shoreline

Indicator #8131

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**
Rationale: **The degree of negative impact to aquatic life in the nearshore will vary depending on the design of the shoreline protection and on the antecedent conditions. Some types of shore protection create conditions that are not hospitable to aquatic life in the nearshore. This indicator measures the extent to which this is occurring.**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis. Table 1 lists percentages of shorelines in each category of hardened shoreline.

Purpose

- To assess the amount of shoreline habitat altered in the Great Lakes by the construction of shore protection including sheet piling, riprap, 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. This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

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.

Shoreline protection has been classified into seven categories with four main categories which include highly protected 70-100%, moderately protected 40-70%, minor protection 15-40%, and no protection which is less than 15% (Fig.1). From this dataset, shoreline hardening has been categorized for each lake and connecting channel (Table 1). Figure 2 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.

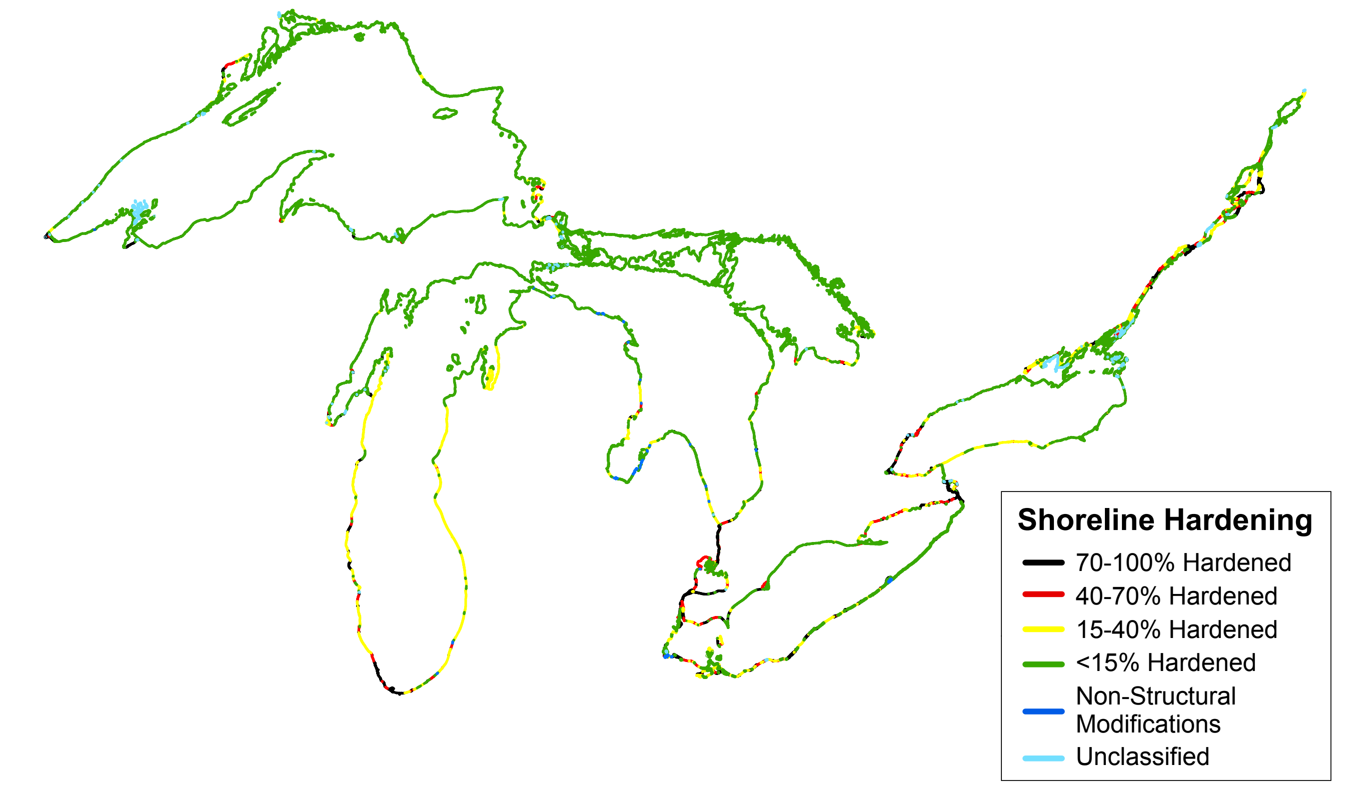

Figure 1. Extent of shoreline hardening in the Great Lakes basin.
Source: National Oceanic and Atmospheric Administration.

Of the lakes themselves, Lake Erie has the highest percentage of its shoreline hardened, and Lakes Huron and Superior have the lowest (Fig. 3). In 1999, Environment Canada assessed change in the extent of shoreline hardening along about 22 kilometers (13.7 miles) of the Canadian shoreline of the St. Clair River from 1991-1992 to 1999. Over the eight-year period, an additional 5.5 km (3.4 mi) (32%) of the shoreline had been hardened. This is clearly not representative of the overall basin, as the St. Clair River is a

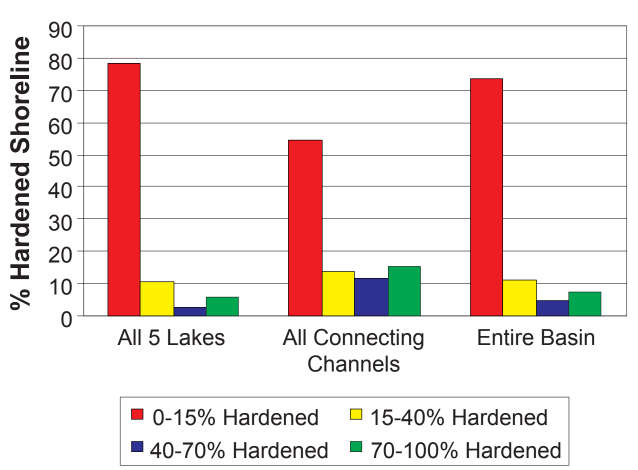

Figure 2. Shoreline hardening in the Great Lakes compiled from 1979 data for the state of Michigan and 1987-1989 data for the rest of the basin.
Source: Environment Canada and National Oceanic and Atmospheric Administration.

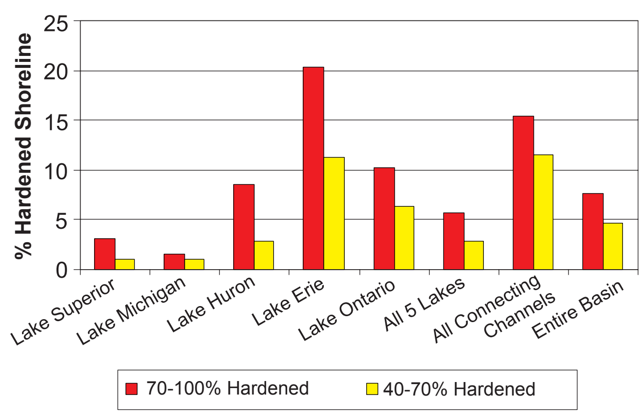

Figure 3. Shoreline hardened by lake compiled from 1979 data for the state of Michigan and 1987-1989 for the rest of the basin.
Source: Environment Canada and National Oceanic and Atmospheric Administration.

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.

narrow shipping channel with high volumes of Great Lakes traffic. This area also has experienced significant development along its shorelines, and many property owners are hardening the shoreline to reduce the impacts of erosion.

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 down current 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.

Comments from the author(s)

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 five years.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes:						

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Last Updated
State of the Great Lakes 2009

Contaminants Affecting Productivity of Bald Eagles
Indicator #8135

This indicator report was last updated in 2005.

Overall Assessment

Status:	**Mixed**
Trend:	**Improving**

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

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
- 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 (United States and Canada 1987).

State of the Ecosystem
As the top avian predator in the nearshore and tributary areas of the Great Lakes, the bald eagle (*Haliaeetus leucocephalus*) 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.

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 (Fig. 1). The number of active bald eagle territories has increased markedly from the depths of the population decline caused by DDE (Fig. 2). Similarly, the percentage of nests producing one or more fledglings (Fig. 3) and the number of young produced per territory (Fig. 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 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.

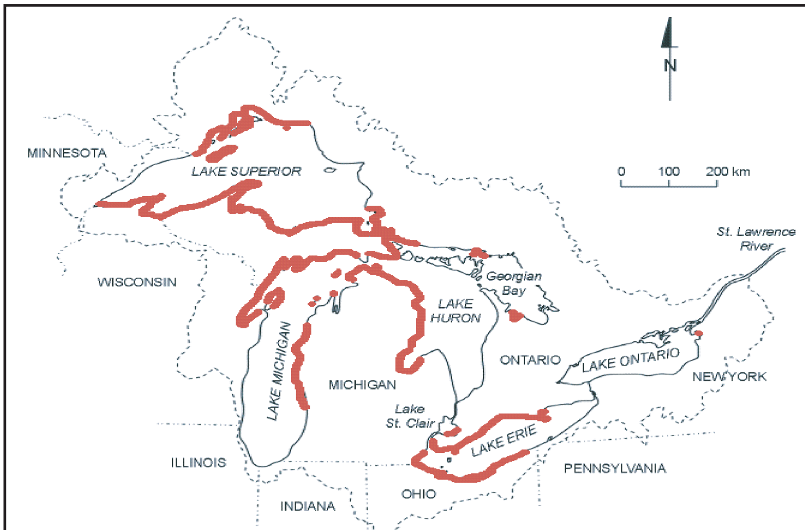

Figure 1. Approximate nesting locations of bald eagles (in red) along the Great Lakes shorelines, 2000.
Source: W. Bowerman, Clemson University, Lake Superior LaMPs, and for Lake Ontario, Peter Nye, and N.Y. Department of Environmental Conservation.

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 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.

Comments from the author(s)

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

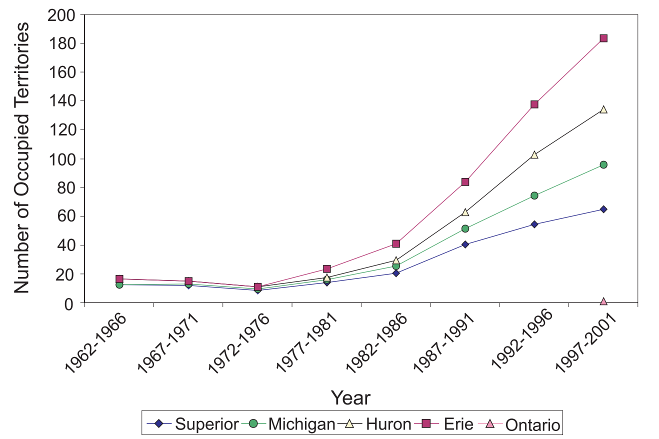

Figure 2. Average number of occupied bald eagle territories per year by lake.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources.

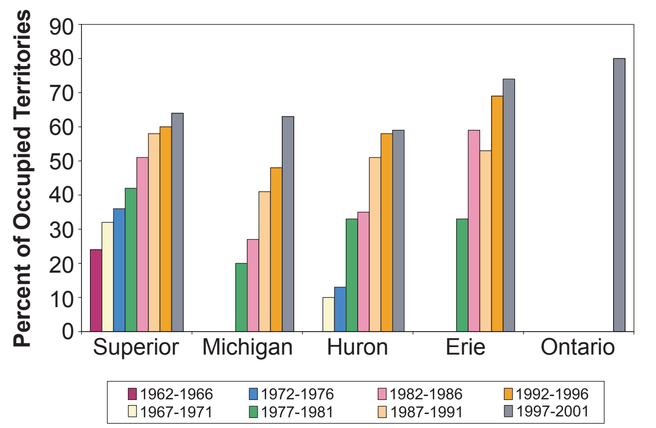

Figure 3. Average percentage of occupied territories fledging at least one young.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources.

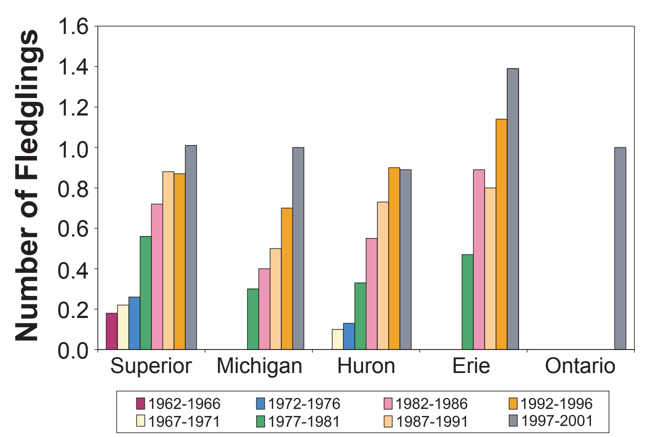

Figure 4. Average number of young fledged per occupied territory per year.
Source: David Best, U.S. Fish and Wildlife Service; Pamela Martin, Canadian Wildlife Service; and Michael Meyer, Wisconsin Department of Natural Resources.

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.

[Editors Note: The U.S. Department of Interior and the USFWS removed the bald eagle from the Federal List of Endangered and Threatened Wildlife and Plants in 2007. The protections provided to the bald eagle under the Bald and Golden Eagle Protection Act (Eagle Act) and the Migratory Bird Treaty Act (MBTA) will continue to remain in place. A set of National Bald Eagle Management Guidelines published by the USFWS (http://www.fws.gov/migratorybirds/BaldEagle.htm) provides guidance to landowners on how to ensure that actions taken on their property are consistent with the Eagle Act and the MBTA.]

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.

Acknowledgments
Authors: Ken Stromborg, U.S. Fish & Wildlife Service;
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Additional data 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.

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Last Updated
State of the Great Lakes 2005

Population Monitoring and Contaminants Affecting the American Otter

Indicator #8147

This indicator report was last updated in 2002.

Overall Assessment

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

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To directly measure the contaminant concentrations found in American otter (*Lontra canadensis*) 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 (IJC) 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 (Fig. 1). Most coastal shoreline areas have more

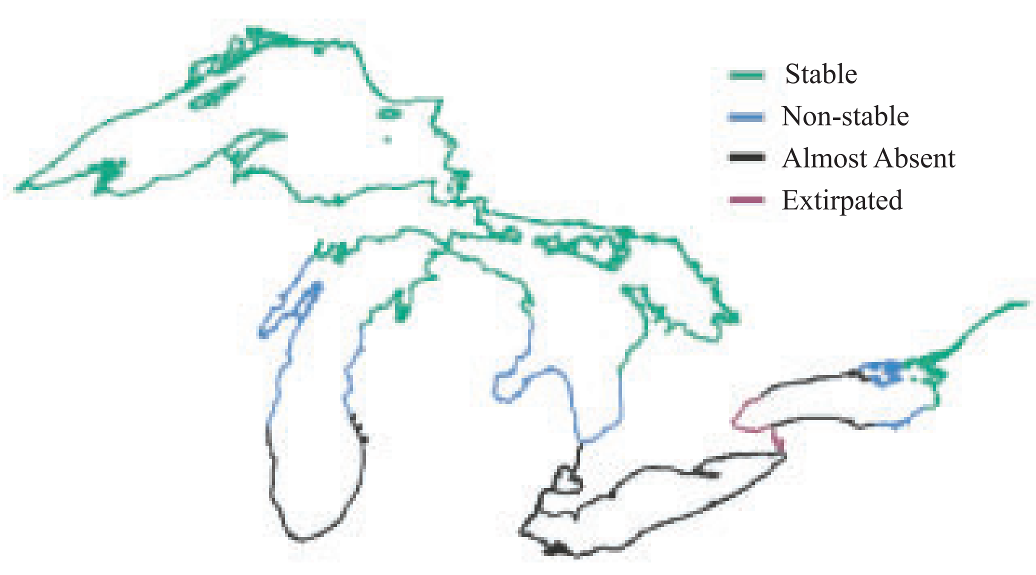

Figure 1. Great Lakes shoreline population stability estimates for the American otter.
Source: Thomas C.J. Doolittle, Bad River Band of Lake Superior Tribe of Chippewa Indians.

suppressed populations than interior zones. Areas of otter population suppression are directly related to human population centers and subsequent habitat loss, and also to elevated contaminant concentrations associated with human activity. Little statistically-viable population data exist for the Great Lakes populations, and all suggested population levels illustrated were determined from coarse population assessment methods.

Pressures

American otters are a direct link to organic and heavy metal concentrations in the food chain. It is a relatively sedentary species and subsequently synthesizes contaminants from smaller areas than wider-ranging organisms, e.g. bald eagle. Contaminants are a potential and existing problem for many otter populations throughout the Great Lakes. Globally, indications of contaminant problems in otter have been noted by decreased population levels, morphological abnormalities (i.e. decreased baculum length) and decline in fecundity. Changes in the species population and range are also representative of anthropogenic riverine and lacustrine habitat alterations.

Management Implications

Michigan and Wisconsin have indicated a need for an independent survey using aerial survey methods to index otter populations in their respective jurisdictions. Minnesota has already started aerial population surveys for otter. Subsequently, some presence-absence data may be available for Great Lakes watersheds and coastal populations in the near future. In addition, if the surveys are conducted frequently, the trend data may become useful. There was agreement among resource managers on the merits of aerial survey methods to index otter populations, although these methods are only appropriate in areas with adequate snow cover. NYDEC, OMNR, Federal jurisdictions and 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.

Comments from the author(s)

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.

Acknowledgments

Author: Thomas C.J. Doolittle, Bad River Band of Lake Superior Tribe of Chippewa Indians, Odanah, WI.

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Last Updated
State of the Great Lakes 2002
[Editor's note: A condensed version of this report was published in the State of the Great Lakes 2003.]

Biodiversity Conservation Sites

Indicator #8164

Note: This is an indicator in development that was proposed for SOLEC 2006.

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **Information on Biodiversity Conservation Sites is limited at this time making the status and trend of this indicator difficult to assess.**

Lake-by-Lake Assessment

Separate lake assessments are not available at this time.

Purpose

- To assess and monitor the biodiversity of the Great Lakes watershed

Ecosystem Objective

The ultimate goal of this indicator is to generate and implement a distinct conservation goal for each target species, natural community type and aquatic system type within the Great Lakes basin. Through establishing the long-term survival of viable populations, the current level of biodiversity within the region can be maintained or even increased. This indicator supports Great Lakes Quality Agreement Annexes 1, 2 and 11 (United States and Canada 1987).

State of the Ecosystem

Background

In 1997, the Great Lakes Program of The Nature Conservancy (TNC) launched an initiative to identify high priority biodiversity conservation sites in the Great Lakes region. Working with experts from a variety of agencies, organizations, and other public and private entities throughout the region, a collection of conservation targets was identified. These targets, which represented the full range of biological diversity within the region, consisted of globally rare plant and animal species, naturally occurring community types within the ecoregion, and all aquatic system types found in the Great Lakes watershed.

In order to ensure the long-term survival of these conservation targets, two specific questions were asked: how many populations or examples of each target are necessary to ensure its long-term survival in the Great Lakes ecoregion, and how should these populations or examples be distributed in order to capture the target's genetic and ecological variability across the Great Lakes ecoregion? Using this information, which is still limited because these questions have not been satisfactorily answered in the field of conservation biology, a customized working hypothesis, i.e., conservation goal, was generated for each individual conservation target. Additionally, to effectively and efficiently achieve these conservation goals, specific portfolio sites were identified. These sites, many of which contain more than one individual target, support the most viable examples of each target, thus aiding in the preservation of the overall biodiversity within the Great Lakes region.

With support from TNC, Nature Conservancy of Canada (NCC) has undertaken a similar initiative, identifying additional targets, goals, and conservation sites within Ontario. However, as the commencement of this project occurred some time after the U.S. counterpart, there is a wide discrepancy in the information that is currently available.

Status of Biodiversity Conservation Sites in the Great Lakes Basin

Within the U.S. portion of the Great Lakes region, 208 species (51 plant species, 77 animal species and 80 bird species) were identified. Of these, 18 plant species and 28 animal species can be considered endemic (found only in the Great Lakes region) or limited (range is primarily in the Great Lakes ecoregion, but also extends into one or two other ecoregions). Furthermore, 24 animals and 14 plants found within the basin are recognized as globally imperiled. Additionally, 274 distinct natural community types are located throughout the ecoregion: 71 of which are endemic or largely limited to the Great Lakes, while 45 are globally

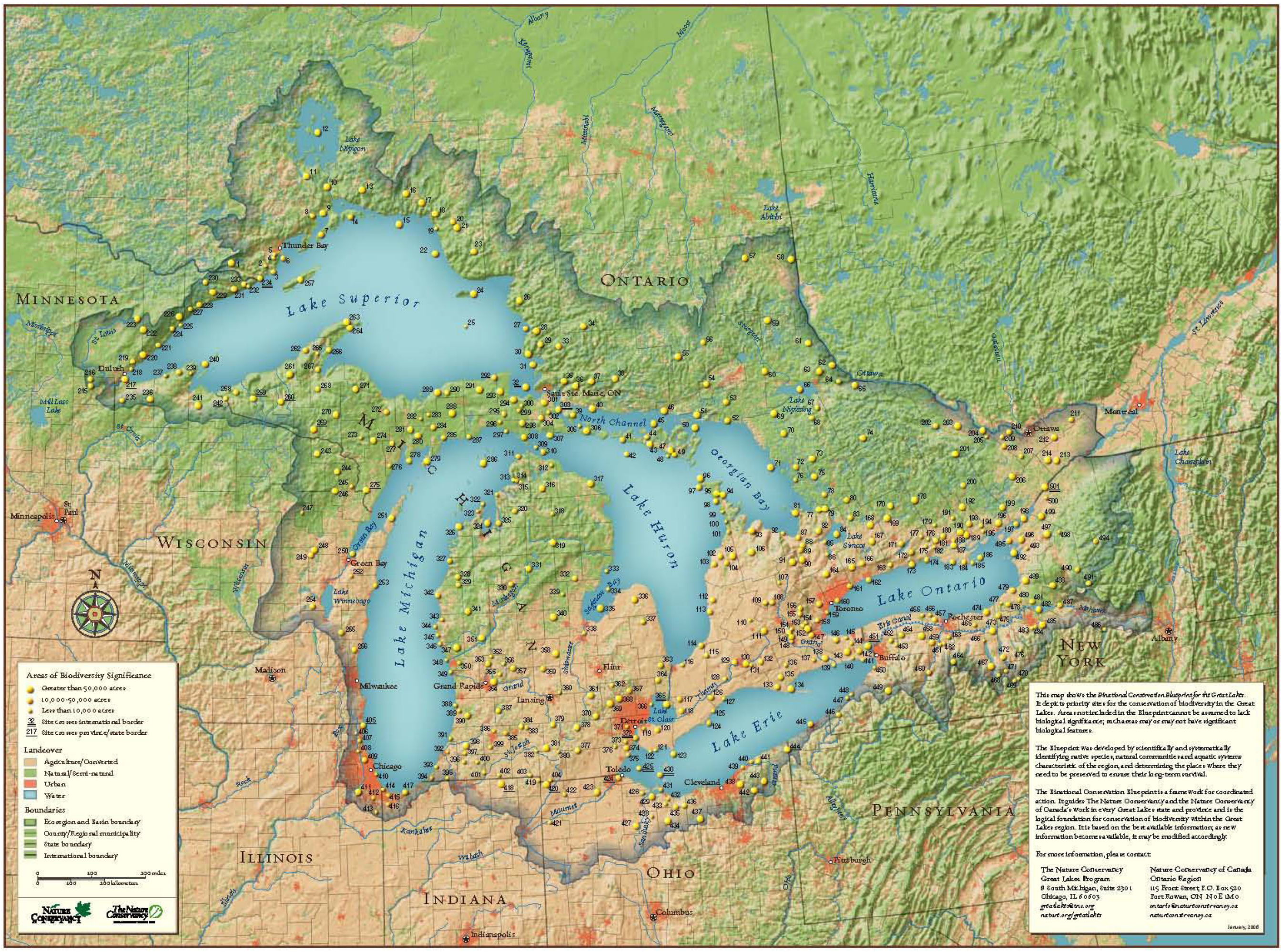

Figure 1. Map of Biodiversity Conservation Sites within the Great Lakes Region.
Source: http://www.nature.org/wherewework/northamerica/greatlakes/files/tnc_great_lakes_web.pdf.

imperiled. The Great Lakes watershed also contains 231 aquatic system types, all of which are inextricably connected to the region, and thus do not occur outside this geographical area.

A total of 501 individual portfolio sites have been designated throughout the Great Lakes region: 280 of which reside fully within the United States, 213 are located entirely in Canada, while the remaining eight sites cross international borders (The Nature Conservancy and Nature Conservancy of Canada 2006a). The number of conservation priority sites found in the United States is not distributed equally among the Great Lake states, since over half are completely or partially located within the state of Michigan. New York State contains the second greatest number of sites with 56; Wisconsin, 29; Ohio, 25; and Minnesota, 20. Furthermore, nine sites are located within the state of Illinois, seven sites in Indiana, while only two sites are found in the state of Pennsylvania (11 sites cross state borders, while one international and one U.S. site cross more than one border). The sizes of the selected portfolio sites have a wide distribution, ranging from approximately 24 to 61,000 hectares (60 to 1,500,000 acres); with three-fourths of the sites having areas which are less than 8,000 hectares (20,000 acres).

The currently established conservation sites provide enough viable examples to fully meet the conservation goals for 20% of the 128 species and 274 community types described within the Great Lakes conservation vision. Additionally, under the existing Conservation Blueprint (The Nature Conservancy and Nature Conservancy of Canada 2006b), 80% of the aquatic systems are sufficiently represented in order to meet their conservation goals. However, these figures might not present an accurate depiction of the current state of the biodiversity within the region. Due to a lack of available data for several species, communities, and aquatic systems, a generalized conservation goal, e.g. "all viable examples" was established for these targets. As such, even though the conservation goals may have been met, there might not be an adequate number of examples to ensure the long-term survival of these targets.

In order to sustain the current level of biodiversity, i.e., number of targets that have met their conservation goals, attention to the health and overall integrity of the conservation sites must be maintained. While approximately 60% of these sites are irreplaceable, these places represent the only opportunity to protect certain species, natural communities, aquatic systems, or assemblages of these targets within the Great Lakes region. Only 5% of all U.S. sites are actually fully protected. Furthermore, 79% of the Great Lakes sites require conservation attention within the next 10 years, while more than one-third of the sites need immediate attention in order to protect conservation targets. These conservation actions range from changes in policies affecting land use, i.e. specific land protection measures (conservation easements or changes in ownership), to the modification of the management practices currently used.

Pressures

In the United States, information was obtained from 224 sites regarding pressures associated with the plants, animals, and community targets within the Great Lakes basin. From these data four main threats emerged. The top threat to biodiversity sites throughout the region is currently development, i.e., urban, residential, second home, and road, because development is affecting approximately two-thirds of the sites in the form of degradation, fragmentation, or even the complete loss of these critical habitats. The second significant threat, affecting the integrity of more than half the sites, is the impact exerted by invasive species, which includes non-indigenous species such as purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phararis arundinacea*), garlic mustard (*Alliaria petiolata*), buckthorn (*Rhamnus cathartica*), zebra mussels (*Dreissena polymorpha*), and exotic fishes, as well as high-impact, invasive, native species such as deer. Affecting almost half of the U.S. sites, the third most common threat to native biodiversity, hydrology alteration, includes threats due to dams, diversions, dikes, groundwater withdrawals, and other changes to the natural flow regime. Finally, recreation (boating, camping, biking, hiking, etc.) is a major threat that affects over 40% of the sites.

Management Implications

A continuous effort to obtain pertinent information is essential in order to maintain the most scientifically-based conservation goals and strategies for each target species, community and aquatic system type within the Great Lakes basin. Additional inventories are also needed in many areas to further assess the location, distribution and viability of individual targets, especially those that are more common throughout the region. Furthermore, even though current monitoring efforts and conservation actions are being implemented throughout the watershed, they are generally site-specific or locally concentrated. A greater emphasis on a regional-wide approach must be undertaken if the long-term survival of these metapopulations (populations of the same species that are distinct, but that can interact) is to be ensured. This expanded perspective would also assist in establishing region-wide communications, thus enabling a more rapid and greater distribution of information. However, the establishment of basin-wide management practices is greatly hindered by the numerous governments represented throughout this region, (two federal governments, 100 tribal authorities, one province, and eight states (each with multiple agencies), 13 regional and 18 county municipalities in Ontario, 192 counties in the United States and thousands of local governments) and the array of land-use policies developed by each administration. Without additional land protection measures, it will be difficult to preserve the current sites and implement restoration efforts in order to meet the conservation goals for the individual conservation targets.

Acknowledgments

Authors: Jeffrey C. May, U.S. Environmental Protection Agency, GLNPO Intern.

Contributors: Mary Harkness, The Nature Conservancy.

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Last Updated

State of the Great Lakes 2007

Forest Lands - Conservation of Biological Diversity

Indicator #8500

Note: This indicator includes four components that correspond to Montreal Process Criterion #1, Indicators 1, 2, 3, and 5.

Indicator #8500 Components:

Component (1) – Extent of area by forest type relative to total forest area
Component (2) – Extent of area by forest type and by age-class or successional stage
Component (3) – Extent of area by forest type in protected area categories
Component (4) – Extent of forest land conversion, parcelization, and fragmentation (*still under development for future analysis; data not presented in this report*)

Overall Assessment

Status: **Mixed**
Trend: **Undetermined**
Rationale: **There is a moderate distribution of forest types in the Great Lakes basin by age-class and seral stage. Overall, the region surrounding the upper Great Lakes is doing good, while areas in the lower Great Lakes have a status that is fair/poor. The lack of a baseline against which to measure the current state complicates a definite status and trend assessment. Additional analysis is required by forestry professionals.**

Lake-by-Lake Assessment

Each lake was categorized with a Not Assessed status and an Undetermined trend, since data by individual lake basin were not available for the United States at this time.

Purpose

- To describe the extent, composition and structure of Great Lakes basin forests
- To address the capacity of forests to perform the hydrologic functions and host the organisms and processes that are essential to protecting the biological diversity, physical integrity and water quality of the watershed

Ecosystem Objective

To have a forest composition and structure that most efficiently conserves the natural biological diversity of the region.

State of the Ecosystem

Component (1): Extent of area by forest type relative to total forest area

Forests cover over half (60%), of the land in the Great Lakes basin. The United States portion of the basin has forest coverage on 51% of its land, while the Canadian portion has coverage on 73% of its land.

According to data from 2006, maple-beech-birch is the most extensive forest type in the United States portion of the basin, representing 7.5 million hectares (18.5 million acres), or 37% of total United States forest area in the basin. Aspen-birch forests constitute the 2nd largest forest type, representing 19% of the United States total. Complete data are available in Table 1 and are visually represented in Figure 1.

According to data from 2002, the Canadian portion of the basin is dominated by mixed forest, representing 39% of the total Canadian forest area, followed by hardwoods, covering 23% of the total Canadian forest area analyzed from satellite data (Table 2A). The most extensive provincial forest type is the upland mixed conifer, representing 23% of the forested area available for analysis, followed by the mixedwoods, tolerant hardwoods, white birch, and poplars (Table 2B, Fig. 2).

Implications for the health of Great Lakes forests and the basin ecosystem are difficult to establish. There is no consensus on how much land in the basin should be forested, or on how much land should be covered by each forest type. Generally speaking, maintenance of the variety of forest types is important in species preservation, and long-term changes in forest type proportions are indicative of changes in forest biodiversity patterns (Ontario Ministry of Natural Resources (OMNR) 2007).

Comparisons to historical forest cover, although of limited utility in developing landscape goals, can illustrate the range of variation experienced within the basin since the time of European settlement. (See supplemental section entitled "Historical Range of Variation in the Great Lakes Forests of Minnesota, Wisconsin and Michigan" in Indicator #8500, Canada and United States (2005) for more information). Analysis of similar historical forest cover data for the entire Great Lakes basin over the past several years would be useful in establishing current trends to help assess potential changes to ecosystem function and community diversity.

Forest Type	Forest Area (ha)	% of Total Forest Area	Protected Area (ha)	% Protected
Maple-Beech-Birch	7,482,643	36.74%	747,033	9.98%
Aspen-Birch	3,791,691	18.62%	217,304	5.73%
Oak-Hickory	2,482,436	12.19%	41,890	1.69%
Spruce-Fir	2,476,314	12.16%	181,385	7.32%
White-Red-Jack Pine	1,691,484	8.30%	124,304	7.35%
Elm-Ash-Cottonwood	1,485,361	7.29%	25,420	1.71%
Oak-Pine	509,163	2.50%	16,701	3.28%
Other*	224,481	1.10%	10,167	4.53%
Nonstocked	224,503	1.10%	9,880	4.40%
Total	20,368,076		1,374,084	6.75%

Table 1. Total forest area and protected area by forest type in U.S. Great Lakes basin counties.
Non-stocked = timberland less than 10% stocked with live trees
"Other" category includes: Loblolly-Shortleaf Pine, Oak-Gum-Cypress, Pinyon-Juniper, Douglas-Fir, Fir-Spruce-Mountain Hemlock, Exotic Softwood, and Exotic Hardwood.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2006 Resource Planning Act (RPA) Assessment Database.

Component (2): Extent of area by forest type and by age-class or successional stage

Succession is technically defined as "the natural sequence of plant community replacement beginning with bare ground and resulting in a final, stable community in which a climax forest is reached. Foresters, wildlife biologists, and farmers battle succession to try to maintain a particular vegetative cover," (United States Department of Agriculture (USDA) 1989). Current data, although not reported by actual successional stage for this report, is available according to age-class.

In the United States portion of the basin, the 41 to 60 and 61 to 80 year age-classes are dominant and together represent about 58% of total timberland area. Forests 40 years of age and under make up a further 28%, while those in the 81-plus year age-classes constitute 13% of total timberland area. Table 3 contains complete United States data (in hectares) for age-class distribution by United States forest type.

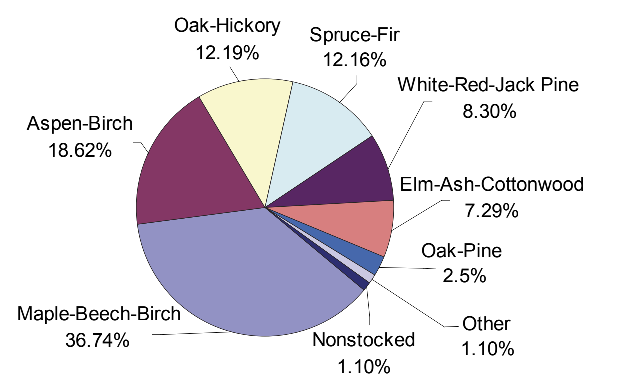

Figure 1. Proportion of forested area by forest type in U.S. Great Lakes basin.
"Other" category includes: Loblolly-Shortleaf Pine, Oak-Gum-Cypress, Pinyon-Juniper, Douglas-Fir, Fir-Spruce-Mountain Hemlock, Exotic Softwood, and Exotic Hardwood.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2006 Resource Planning Act (RPA) Assessment Database.

Because forests are dynamic and different tree species have different growth patterns, depending on the disturbance regime and regeneration type, age distribution varies by forest type. In the United States portion of the basin, aspen-birch forests tend to be younger, being more concentrated than other forest types in age classes under 40 years, while the maple-beech-birch forests are more concentrated in the 41 to 60 and 61 to 80 year age classes, comparatively. Spruce-fir and white-red-jack pine forests have a well-distributed age structure, and also have the highest proportion of old trees, with about 10% and 5% of the total area of their forest type in the 100-plus year age class respectively (Fig. 3).

These age-class data can serve as a coarse surrogate for the vegetative structure (height and diameter) of a forest, and they can be combined with data from other indicators to provide insight on forest sustainability.

A) Canadian Great Lakes Basin				
Satellite Classes	**Forest Area (ha)**	**% of Total Forest Area**	**Protected Area (ha)**	**% Protected**
Forest - Sparse	2,053,869	13.78%	245,118	11.93%
Forest - Hardwood	3,468,513	23.27%	361,147	10.41%
Forest - Mixed	5,750,313	38.57%	649,342	11.29%
Forest - Softwood	2,407,729	16.15%	268,753	11.16%
Swamp - Treed	49,933	0.33%	1,413	2.83%
Fen - Treed	30,197	0.20%	3,726	12.34%
Bog - Treed	436,083	2.93%	28,128	6.45%
Disturbed Forest - cuts	578,450	3.88%	8,973	1.55%
Disturbed Forest - burns	97,545	0.65%	18,628	19.10%
Disturbed Forest - regenerating	35,987	0.24%	381	1.06%
Totals	14,908,617		1,585,608	10.64%

B) AOU* Portion of Ontario				
Provincial Forest Type	**Forest Area (ha)**	**% of Total Forest Area**	**Protected Area (ha)**	**% Protected**
White Birch	1,593,114	13.73%	175,261	11.00%
Mixed Conifer Lowland	1,048,126	9.03%	60,192	5.74%
Mixed Conifer Upland	2,657,086	22.90%	239,194	9.00%
Mixedwood	2,099,760	18.10%	194,682	9.27%
Jack Pine	714,165	6.15%	54,991	7.70%
Poplar	1,189,573	10.25%	75,538	6.35%
Red & White Pine	685,124	5.90%	105,682	15.43%
Tolerant Hardwoods	**1,616,502**	**13.93%**	**108,993**	**6.74%**
Totals	**11,603,450**		**1,014,533**	**8.74%**

Table 2. Total forest area and protected area by forest type in, A) Canadian Great Lakes basin, B) AOU* portion of Ontario.
* The Area of the Undertaking (AOU) land area represents 72% of the total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

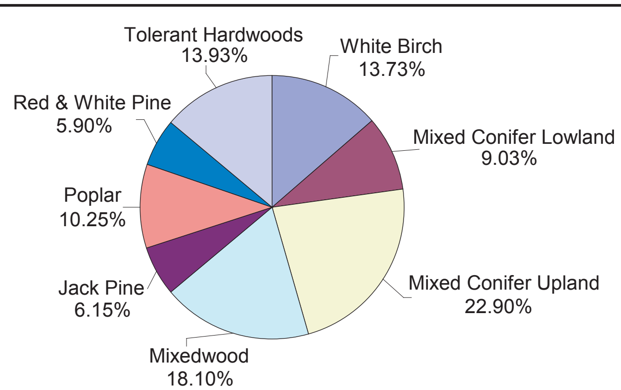

Figure 2. Proportion of forested area by provincial forest type in AOU* portion of Canadian Great Lakes basin.
* The Area of the Undertaking (AOU) land area represents 72% of the total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

United States data on the extent of forest area by successional or seral stage are not available, although data can be obtained according to forest size class, which is directly comparable to the age-class data presented here. Certain tree species can be associated with the various successional stages, but a standard and quantifiable protocol for identifying successional stage has not yet been developed therefore complicated reporting according to this metric. 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 more late-successional types, such as maple-beech-birch.

Ontario's forests have a distribution leaning towards mature stages, representing about 50% of the total forest area analyzed. Forests in the immature stage make up the next largest group with 20% of the total, followed by those in late successional with 14%. Every Canadian forest type distribution follows this general trend except for jack pine. Complete available data for Ontario can be viewed in Table 4 and are visually represented in Figure 4.

Although the implications of these age-class data for forest and basin health overall are unclear, water quality is generally most affected immediately following a disturbance from harvest or natural event when increased concentrations of nutrients in stream water can sometimes be detected. Following such disturbances, however, concentrations of nutrients often remain within acceptable limits for drinking water quality. In landscapes containing a mosaic of forest successional stages, use of forestry Best Management Practices (e.g., retention of forested buffers along streams) ensures that any increases in flow, sediment, or nutrients are minor and short-term and that increases are similar to those following natural disturbance (Comerford *et al.* 1992, Fisher and Binkley 2000, Ice 2004, McBroom *et al.* 2003).

<u>Component (3): Extent of area by forest type in protected area categories</u>

It is difficult to assess the implications of the extent of protected forest area, since there is no consensus on how "protected" should be defined or what the actual proportion should be. Differences among the United States, Canadian, and International Union for the Conservation of Nature (IUCN) definitions of protected areas should be noted. The IUCN standard contains six categories of protected areas—strict nature reserves/wilderness areas, national parks, natural monuments, habitat/species management areas, protected landscapes/seascapes, and managed resource protection areas. The U.S. Forest Service Forest Inventory and Analysis Program defines protected areas as forests "reserved from harvest by law or administrative regulation," including designated Federal Wilderness areas, National Parks and Lakeshores, and state designated areas (Smith 2004). Ontario defines protected areas as national parks, conservation reserves, and its six classes of provincial parks – wilderness, natural environment, waterway, nature reserve, historical and recreational (OMNR 2002). There is substantial overlap among the specific United States, Ontario and IUCN definitions, and a more consistent classification system would ensure proper accounting of protected areas.

Forest Type	Age Class (in years)					
	0-20	21-40	41-60	61-80	81-100	100+
Maple-Beech-Birch	6.26%	11.51%	30.23%	37.35%	12.26%	2.39%
Aspen-Birch	24.37%	25.16%	28.68%	18.18%	3.11%	0.50%
Oak-Hickory	7.23%	17.27%	30.63%	27.55%	14.09%	3.22%
Spruce-Fir	5.57%	11.45%	28.29%	30.91%	14.23%	9.55%
White-Red-Jack Pine	11.16%	23.35%	32.62%	20.29%	7.54%	5.05%
Elm-Ash-Cottonwood	7.97%	20.53%	36.82%	22.82%	8.28%	3.58%
Oak-Pine	13.76%	25.01%	32.94%	20.37%	6.43%	1.48%
Other*	11.82%	34.11%	38.21%	15.27%	0.58%	0.00%
Nonstocked East	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total	11.51%	16.96%	30.29%	28.13%	9.90%	3.22%

Table 3. Age-class distribution as a percentage of forested area within forest type on timberland for U.S. Great Lakes basin counties.
Non-stocked = timberland less than 10% stocked with live trees
"Other" category includes: Loblolly-Shortleaf Pine, Oak-Gum-Cypress, Pinyon-Juniper, Douglas-Fir, Fir-Spruce-Mountain Hemlock, Exotic Softwood, and Exotic Hardwood.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2006 Resource Planning Act (RPA) Assessment Database.

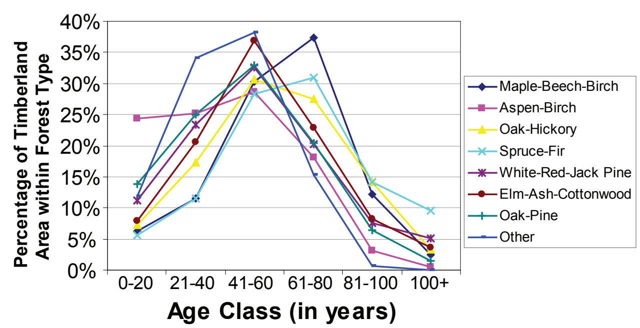

Figure 3. Age-class distribution as a percentage of forested area within forest type on timberland for U.S. Great Lakes basin counties.
"Other" category includes: Loblolly-Shortleaf Pine, Oak-Gum-Cypress, Pinyon-Juniper, Douglas-Fir, Fir-Spruce-Mountain Hemlock, Exotic Softwood, and Exotic Hardwood.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2006 Resource Planning Act (RPA) Assessment Database.

Common to the United States, 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. Protected area status does not necessarily imply that natural disturbance regimes are allowed to function. In many cases, protected status was bestowed onto forests for their scenic or recreational value, which may not contribute significantly to conservation or watershed management goals. On the other hand, forests available for harvest, whether controlled by the national forest system, state or local governments, tribal governments, industry or private landowners, can be managed with the stated purpose of conserving forest and basin health through the implementation of Best Management Practices and certification under sustainable forestry programs. (For more information, refer to *Indicator #8503*, *Forest Lands–Conservation and Maintenance of Soil and Water Resources*).

In the United States basin, 6.8% of forested land is in a protected area category. Forest types with the highest proportion considered to have protected status are maple-beech-birch (9.98%), white-red-jack-pine (7.35%), spruce fir (7.32%) and aspen-birch (5.73%) Please refer to Table 1 for complete United States data.

In the entire Canadian portion of the basin, 10.6% of forest area, or 1.6 million hectares (4.0 million acres), are protected (Table 2A). For the region of Ontario that has available forest type data, protection rates range from 15.4% for red and white pine and 11% for white birch, to 6.4% for poplar and 5.7% for mixed conifer lowland forests (Table 2B).

Provincial Forest Type	Seral Stage				
	Presapling	Sapling	Immature	Mature	Late Successional
White Birch	3.49%	4.52%	15.55%	63.58%	12.87%
Mixed Conifer Lowland	13.81%	9.31%	13.38%	47.00%	16.50%
Mixed Conifer Upland	5.91%	13.12%	22.51%	42.11%	16.36%
Mixedwood	4.60%	7.92%	26.06%	51.03%	10.39%
Jack Pine	8.60%	31.96%	29.24%	27.51%	2.69%
Poplar	6.60%	10.45%	18.97%	52.55%	11.43%
Red & White Pine	4.94%	3.77%	23.28%	62.95%	5.06%
Tolerant Hardwoods	1.23%	0.87%	6.40%	60.13%	31.37%
Totals	6.00%	10.14%	20.12%	49.84%	13.91%

Table 4. Seral stage distribution of provincial forest types (in hectares) in AOU* portion of Canadian Great Lakes Basin.
* The Area of the Undertaking (AOU) land area represents 72% of the total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

National forest protection rates are estimated to be 8.4% in Canada (WWF 1999) and 14% in the United States (USDA Forest Service 2004). Despite the fact that updated trend data for protected status are not available at this time for the Great Lakes basin, earlier analyses have shown a recent general increase in protected areas (indicator reports #8500 in Canada and the United States 2005 and 2007).

As for the range of variation in protection rates by forest types, protected areas should be representative of the diversity in forest composition within a larger area. However, defining what constitutes this "larger area" is problematic. Policymakers often have a different jurisdiction than the Great Lakes basin in mind when deciding where to locate protected areas. Also, the tree species and forest types found on an individual plot of protected land can change over time due to successional processes.

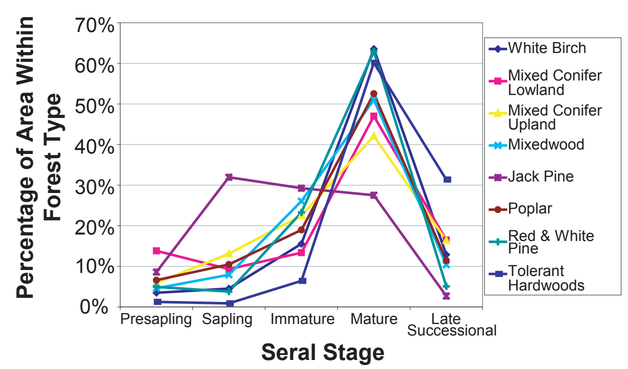

Figure 4. Seral stage distribution as a percentage of forested area within provincial forest type in AOU* portion of Canadian Great Lakes Basin.
* The Area of the Undertaking (AOU) land area represents 72% of total land area analyzed in Ontario's portion of the Great Lakes basin.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

Component (4): Extent of forest land conversion, parcelization, and fragmentation

This component is still under development, as consensus has not been reached on definitions of forest fragmentation metrics and which ones are therefore suitable for reporting. The proposed structure is split into the forces that drive fragmentation, (land conversion and parcelization) and a series of forest spatial pattern descriptions based on (as yet to be agreed upon) fragmentation metrics.

Provincial Forest Type	Description
White Birch	predominantly white birch stands
Upland Conifers	predominantly spruce and mixed jack pine/spruce stands on upland sites
Lowland Conifers	predominantly black spruce stands on low, poorly drained sites
Mixedwood	mixed stands made up mostly of spruce, jack pine, fir, poplar and white birch
Jack Pine	predominantly jack pine stands
Poplar	predominantly poplar stands
White and Red Pine	all red and white pine mixedwood stands
Tolerant Hardwoods	predominantly hardwoods such as maple and oak, found mostly in the Great Lakes forest region

Table 5. Description of Canadian provincial forest types.
Source: Forest Resources of Ontario 2001: State of the Forest Report, Appendix 1, p. 41, (OMNR 2002).

Conversion of forest land to other land-use classes is considered to be a major cause of fragmentation. Proposed metrics to describe this include the percent of forest lands converted to and from developed, agricultural, and pasture land uses. Both Canadian and United States data are available and can be obtained from the Ontario Ministry of Natural Resources and the USDA Natural Resources Conservation Service, Natural Resources Inventory, respectively.

Parcelization of large areas of forest lands in single ownerships into smaller separately owned tracts of land can lead to a disruption of continuous ecosystems and habitats and, therefore, increased fragmentation. A proposed metric is the average size of land holdings. Canada does not have available data for this metric, while the United States data are available through the USDA Forest Service, Forest Inventory and Analysis National Woodland Owner Survey.

Data for various fragmentation metrics exists for both Canada and the United States, but the way these metrics are viewed is drastically different. According to sources that have compiled United States data, fragmentation, ". . . is viewed as a property of the landscape that contains forest… [as opposed to] a property of the forest itself." (Riitters et. al 2002). Ontario data are compiled according the latter view of fragmentation and exist for the following metrics: area, patch density and size, edge, shape, diversity and interspersion, and core area. United States data exist for patchiness, perforation, connectivity, edge, and interior or core forest, and they are available from the USDA Forest Service. They are also being compiled by U.S. EPA. Substantial discussion is still required to refine these metrics before reporting and analysis of this component can continue on a basin-wide scale.

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. Climate change in the Great Lakes region will also affect forest biodiversity and distribution of forest types by shifting the ranges of various tree species.

Additional disturbances caused by lumber removal and forest fires can also alter the structure of Great Lakes basin forests.

Management Implications
Increased communication and agreement regarding the definitions, data collection methods, and reporting methods for forest type, successional stage, protected area category and fragmentation metrics between the United States and Canada would facilitate more effective basin-wide analyses.

Reporting of United States forest data according to watershed as opposed to county would enable analysis by individual lake basin, therefore increasing the data's value in relation to specific water quality and biodiversity objectives.

Canadian data by forest type and seral stage for the entire Great Lakes basin in Ontario, as opposed to just the Area of the Undertaking (or AOU, as further described below in the "Comments" section), would allow for a more complete analysis. This can only be accomplished if managers decide to extend forest planning inventories into the private lands in the southern regions of the province.

Managing forest lands in ways that protect the continuity of forest cover can allow for habitat protection and wildlife species mobility, therefore maintaining natural biodiversity.

Comments from the author(s)
Stakeholder discussion will be critical for identifying pressures and management implications, particularly those on a localized basis, that are specific to Great Lakes basin forests. These discussions will add to longstanding debates on strategies for sustainable forest management.

There are significant discrepancies within and between Canadian and United States data that made the analysis of data across the entire Great Lakes basin difficult. The most pervasive problems are related to the time frame, frequency and location of forest inventories and differences in metric definitions.

Canadian Great Lakes data for provincial forest type and seral stage are only available in areas of Ontario where Forest Resources Planning Inventories occur. This region is commonly referred to as the Area of the Undertaking (AOU) and only represents about 72% of Ontario's total Great Lakes basin land area. The remainder of Ontario's forests can only be analyzed using satellite data, which is meant for general land use/land cover analysis and does not have a fine enough resolution to allow for more detailed investigation. As for inventory in the area south of the AOU, there are still no concerted efforts in place to complete a forest resource inventory like the one within the AOU.

Forest inventory time frames for the United States also have an effect on data consistency. Although the 2006 Resource Planning Act assessment was used as the data source for the United States portion of this report, it actually draws data from a compilation of numerous state inventory years as follows: Illinois (2002-2006), Indiana (2002-2006), Michigan (2002-2006), Minnesota (2002-2006), New York (2002-2005), Ohio (2001-2006), Pennsylvania (2002-2006), and Wisconsin (2002-2006). Additional forest types are now measured, that were not in 2002, therefore complicating trend analysis over time. Some challenges related to consistency should diminish as the FIA Program completes its switch to an annualized survey cycle and future analyses incorporate these data.

Also, United States data provided for this report were compiled by county and not by watershed, so the area of land analyzed is not necessarily completely within the Great Lakes basin and all related values are therefore skewed. This factor also made it impossible to represent the data by individual lake basin. Additional GIS analysis of the raw inventory data would be required to provide forest data by watershed.

Definition of forest type differs between the United States and Canada as well. In the United States, forest cover type is defined according to the predominant tree species and is divided into fifteen major groups. The Canadian provincial forest type classifications reported here, however, are based on a combination of ecological factors including dominant tree species, understory vegetation, soil, and associated tree species (OMNR 2002). The definitions of each provincial forest type are available in Table 5.

Standardization of forest type definitions between the United States and Ontario may be necessary for analysis across the entire Great Lakes basin; however, data standardization may not be achievable because programs have evolved to meet the needs of each agency. Establishing clear objectives and bringing data to bear on the objectives would be a step in targeting achievements.

As previously mentioned in this report, the forest fragmentation component of this indicator needs additional refining before it can be included for analysis. In addition, the successional/seral stage discussion needs to continue in order to further clarify this indicator.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin				X		
5. Data obtained from sources within the U.S. are comparable to those from Canada				X		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes: GIS analysis of the United States Data is necessary to accurately report on this indicator for the Great Lakes basin. (Presented United States data are for all counties within the Great Lakes basin).						

Acknowledgments

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Last Updated
State of the Great Lakes 2009

Forest Lands - Maintenance of Productive Capacity of Forest Ecosystems
Indicator #8501

Note: This indicator includes three components and corresponds to Montreal Process Criterion 2, Indicators 10, 11, and 13.

Indicator #8501 Components:
- Component (1) – Area of forest land and area of forest land available for timber production
- Component (2) – Total merchantable volume of growing stock on forest lands available for timber production
- Component (3) – Annual removal of wood products compared to net growth, or the volume determined to be sustainable (*proposed for future analysis; data not presented in this report*)

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **Additional discussion amongst forestry experts is needed for an assessment determination.**

Lake-by-Lake Assessment

Each lake was categorized with a Not Assessed status and an Undetermined trend, since data by individual lake basin were not available for the United States at this time.

Purpose
- To determine the capacity of Great Lakes forests to produce wood products
- To allow for future assessments of changes in productivity over time, which can be representative of social and economic trends affecting management decisions and can also be related to ecosystem health

Ecosystem Objective
To maximize the productive capacity of Great Lakes forests while maintaining the health and sustainability of the ecosystem.

State of the Ecosystem
Component (1): Area of forest land and area of forest land available for timber production
The total area of forest land analyzed in the Great Lakes basin for this report was 35,276,693 hectares (87 million acres). Of this area, about 89% (or a total of 31,556,015 hectares (78 million acres)) can be considered as available for timber production, as calculated from U.S. timberland estimates and Canadian productive forests not restricted from harvesting. In the U.S. portion of the basin, the proportion of land available for timber production was about 92%, while 86% of the entire Canadian forested portion of the basin was available. For just the managed portion of Ontario's forests, 91% was available for timber production. Complete U.S. data broken down by state and Canadian data broken down by lake basin can be viewed in Tables 1 and 2, respectively. These data include potentially inaccessible (areas with no roads) and inoperable areas (areas with steep slope, etc.), areas where landowners do not have timber production as an ownership objective, areas where no markets exist or where are transportation costs to markets are prohibitive, or where other constraints exist (e.g., urbanization). Therefore, these data are an overestimate of the timberland actually available for timber harvest.

The amount of forest land available for timber production is directly related to the productive capacity of forests for harvestable goods. This proportion is affected by different types of management activities, which provides an indication of the balance between the need for wood products with the need to satisfy assorted environmental concerns aimed at conservation of biological diversity.

Component (2): Total merchantable volume of growing stock on forest lands available for timber production
In the analyzed area of Great Lakes basin forests that were available for timber production, 79% of the total wood volume was merchantable. This percentage of growing stock included 93% for the U.S. portion of the basin and 61% for Ontario's managed forests in the Canadian part of the basin. Complete U.S. data broken down by state and Canadian data broken down by lake basin

can be viewed in Tables 3 and 4, respectively.

If the values of net merchantable volume are compared to the total area of forest land available for timber production, a rough estimate of the forests' productive capacity can be obtained. Calculations show the per-unit-area productivity of U.S. Great Lakes forests at 97.4 m^3/ha and of Canadian Great Lakes forests at 90.2 m^3/ha.

State	Total Area of Forest Land (ha)	Area of Forest Land Available for Timber Production* (ha)	% Available for Timber Production
Illinois	36,997	19,521	52.76%
Indiana	207,157	194,947	94.11%
Michigan	7,909,418	7,698,268	97.33%
Minnesota	3,301,085	2,886,868	87.45%
New York	4,860,816	3,984,963	81.98%
Ohio	719,884	671,463	93.27%
Pennsylvania	236,158	229,803	97.31%
Wisconsin	3,096,561	3,056,529	98.71%
Total	20,368,076	18,742,362	92.02%

Table 1. Area of forest land available for timber production* in relationship to total area of forest land in U.S. Great Lakes basin counties.
*Timberland was used as proxy for net area available for timber production in the calculation of these values, but timberland area may include currently inaccessible and inoperable areas, or areas where timber production is not an objective, and is therefore an overestimate of the net area available for timber production.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2006 Resource Planning Act (RPA) Assessment Database.

Changes in productivity values can be indicative of the ecosystem's health and vigor, as a lowered ratio of merchantable volume to available timberland can suggest reduced growth and ability of trees to absorb nutrients, water and solar energy and increased disease and tree mortality. Alternatively, changes in net merchantable volume can also occur due to changes in forest age structure following natural disturbance, harvest, or other events. In such cases, ecosystem health and vigor could still be high. Further assessment of productive capacity would require additional historical data and analysis by forestry experts.

A) Canadian Great Lakes Basin			
Lake Basin	Total Area of Forest Land (ha)	Net area of Forest Land Available for Timber Production (ha)	% Available for Timber Production
Superior	7,061,238	6,006,356	85.06%
Huron	6,162,419	5,343,401	86.71%
Erie	322,317	291,107	90.32%
Ontario	1,362,643	1,172,788	86.07%
Totals	14,908,617	12,813,653	85.95%
B) AOU* Portion of Ontario			
Lake Basin	Total Area of AOU's Forest Land (ha)	Net area of AOU Forest Land Available for Timber Production (ha)	% Available for Timber Production
Huron	4,710,406	4,227,743	89.75%
Ontario	665,100	611,268	91.91%
Superior	6,227,943	5,749,905	92.32%
Totals	11,603,450	10,588,917	91.26%

Table 2. Area of forest land available for timber production in relationship to total area of forest land in, A) Canadian Great Lakes basin, and B) the AOU* portion of Ontario.
* The Area of the Undertaking (AOU) land area represents 72% of Ontario's total Great Lakes basin land area and 78% of its total forest area.
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

Component (3): Annual removal of wood products compared to net growth, or the volume determined to be sustainable

The growth to removal ratio is often used as a coarse surrogate for the concept of sustainable production in the United States. Although exact data for this measure have not been compiled for this report, nationwide U.S. studies have shown that timber growth has exceeded removals for several decades, and Ontario's wood removals on managed timberland is done within sustainable limits by definition of the forestry practices enacted in those areas. On Ontario Crown lands (lands owned by the public) an "Available Harvest Area" is calculated and an estimate of the volume associated with this area is determined. According to the Crown Forest Sustainability Act, one cannot harvest more area (and associated volume) than what is sustainable. Available harvest areas and volumes are determined in modeling and woodflow, with constraints for regeneration capacity, social, economic, and environmental concerns. Both Canada and the United States strive for sustainability as represented by the "Criteria and Indicators of Sustainable Forest Management" of the Montreal Process. The issue of sustainable forests on private lands is not well addressed in Ontario although there are voluntary programs available for private land forestry.

State	Total Live Volume* (m^3) on Forest Lands Available for Timber Production	Net Merchantable Volume (m^3) of Growing Stock*	Volume (m^3) of Non-merchantable Timber †	% Growing Stock* (of Total Vol. Available for Timber Production)
Illinois	3,360,453	3,110,770	249,684	92.57%
Indiana	26,407,920	23,129,912	3,278,009	87.59%
Michigan	853,962,360	793,711,687	60,250,673	92.94%
Minnesota	211,444,949	197,463,596	13,981,353	93.39%
New York	432,587,794	404,895,614	27,692,180	93.60%
Ohio	87,298,965	80,118,896	7,180,069	91.78%
Pennsylvania	34,179,733	32,387,008	1,792,725	94.76%
Wisconsin	311,159,345	290,277,011	20,882,334	93.29%
Total	1,960,401,519	1,825,094,493	120,826,036	93.10%

Table 3. Total volume of growing stock* in U.S. Great Lakes basin counties.
* Calculations do not take inaccessibility or inoperability of timberland into account, so resulting values are skewed high.
† Non-merchantable timber includes rough and rotten cull.
Source: USDA Forest Service, Forest Inventory and Analysis National Program, 2006 Resource Planning Act (RPA) Assessment Database.

Lake Basin	Total Volume (m^3) on Forest Lands Available for Timber Production	Net Merchantable Volume (m^3) of Growing Stock	Volume (m^3) of Non-merchantable Timber	% Growing Stock (of Total Vol. Available for Timber Production)
Huron	667,854,390	421,077,634	246,776,756	63.05%
Ontario	114,963,698	72,717,983	42,245,715	63.25%
Superior	787,640,995	461,410,679	326,230,315	58.58%
Totals	1,570,459,083	955,206,296	615,252,787	60.82%

Table 4. Total volume of growing stock in Canadian Great Lakes basin*.
* Data only available for Ontario's managed forests (AOU portion of Ontario).
Source: Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

Pressures

Fluctuating marketplace demands for wood products and increased pressures to reserve forest lands for recreation, conservation of biodiversity, and wildlife habitat can affect the volume of timber available for harvest.

Disease and disturbance from fires or other events can also affect productivity capacity.

Management Implications

Timber productivity can be increased through the use of timber plantations and sustainable management of forests available for timber production.

Continued discussion of the meaning of sustainability and how it is affected by wood product removal is crucial to the effectiveness of future management decisions.

Comments from the author(s)

It can be difficult to analyze forest areas and growing stocks for a set moment in time, because inventory time frames can vary. United States 2006 Resource Planning Act (RPA) data are compiled from a range of different years (2001 through 2006 for Great Lakes states) depending on when the most recent state inventories were conducted. This issue should diminish as the U.S. Forest Service Forest Inventory and Analysis Program (FIA) completes its switch to an annualized survey cycle, and future analyses incorporate these data.

Canadian data are available by watershed. United States forest data are compiled by county for this report, so the area of U.S. land analyzed is not necessarily completely within the Great Lakes basin. Corresponding data may be skewed. This factor makes it difficult to represent the data by individual lake basin. Additional GIS analysis of the U.S. raw inventory data would be required to provide forest data by watershed.

Area of timberland in the United States is used as a proxy for the net area of land available for timber production in U.S. data calculations, but timberland area may include currently inaccessible and inoperable areas, areas where landowners do not have timber production as an ownership objective, areas where no markets exist or where are transportation costs to markets are prohibitive, or where other constraints exist (e.g., urbanization), and is therefore an overestimation of the net area available for timber production and associated merchantable wood volumes.

Canadian data for growing stock are only available for Ontario's managed forests where Forest Resources Planning Inventories occur. This area is commonly referred to as the Area of the Undertaking (AOU), and only represents 72% of Ontario's total Great Lakes basin land area and 78% of its total forest area. Analysis of the rest of the Canadian part of the basin is restricted to satellite data capabilities.

Data for annual removal of wood products as compared to net growth are available for Canada and a few of the U.S. Great Lakes states, but were not prepared for the Great Lakes basin at the time of this report. This information should be compiled for future analyses when available, and is an important ratio to monitor over time to ensure that wood harvesting is not reducing the total volume of trees on timberland at larger spatial scales. Unfortunately, this value does not add much insight to the detailed ecological attributes of sustainability, and must be analyzed with additional biological components to achieve this indicator's ecosystem objective.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin				X		
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes: GIS analysis is necessary for the U.S. data to accurately report on this indicator for the Great Lakes basin (data presented are for all counties within the Great Lakes basin).						

Acknowledgments

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Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section. Landsat Data based on Landcover 2002 (Landsat 7) classified imagery, Inventory data based on Forest Resources Planning Inventories, and several common NRVIS coverages such as watersheds, lakes and rivers etc. Data supplied by Larry Watkins, Ontario Ministry of Natural Resources.

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Last Updated
State of the Great Lakes 2009

Forest Lands - Conservation and Maintenance of Soil and Water Resources

Indicator #8503

Note: This indicator includes two components and corresponds to Montreal Process Criterion 4, Indicator 19.

Indicator #8503 Components:

Component (1) – Percent of riparian zones and total watershed land that is forested by lake basin

Component (2) – Change in area of forest lands certified under sustainable forestry programs in Great Lakes states and Ontario

Overall Assessment

Status: **Mixed**

Trend: **Undetermined/Improving**

Rationale: **Trend information is not available for Component 1 (percent of riparian zones and watershed areas that are forested) at this time. Data for Component 2 show that the overall area of certified lands is increasing in Great Lakes states and the province of Ontario through numerous certification systems.**

Lake-by-Lake Assessment

Lake Superior

Status: Good

Trend: Undetermined

Rationale: A large proportion of the basin's riparian zones and watersheds are forested. Certification data do not exist specific to this individual lake basin.

Lake Michigan

Status: Mixed

Trend: Undetermined

Rationale: Over half of the basin's riparian zones and watersheds are forested. Certification data do not exist specific to this individual lake basin.

Lake Huron

Status: Mixed

Trend: Undetermined

Rationale: Over half of the basin's riparian zones and watersheds are forested. Certification data do not exist specific to this individual lake basin.

Lake Erie

Status: Poor

Trend: Undetermined

Rationale: Only a small portion of the basin's riparian zones and watersheds are forested. Certification data do not exist specific to this individual lake basin.

Lake Ontario

Status: Mixed

Trend: Undetermined

Rationale: Over half of the basin's riparian zones and watersheds are forested. Certification data do not exist specific to this individual lake basin.

Purpose

- To describe the extent to which Great Lakes basin forests aid in the conservation of the basin's soil resources and protection of water quality
- To describe the level of participation by Great Lakes states and Ontario in sustainable forestry certification programs

Ecosystem Objective

Improved soil and water quality within the Great Lakes basin.

State of the Ecosystem

Component (1): Percent of riparian zones and total watershed land that is forested by lake basin

Forests cover about 60% of the total land and 69% of the riparian zones (defined as the 30 meter buffer around all surface waters) within the Great Lakes basin. The U.S. portion of the basin (including the upper St. Lawrence River watersheds) has forest coverage on 60% of its riparian zones (as of 2001), and the Canadian portion of the basin (excluding the upper St. Lawrence River watersheds) has forest coverage on 76% of its riparian zones (as of 2002) (Table 1). Lake Superior has the greatest coverage overall, with forested lands covering 96% of its riparian zones. Lake Michigan (63%), Lake Huron (73%) and Lake Ontario (59%) all have at least half of their total riparian zones covered with forests, while Lake Erie has only 29% coverage. The percentages of forested riparian zones by watershed are visually represented in Figure 1 and are summarized by Lake basin in Figure 2. In each major lake basin and the upper St. Lawrence River watersheds, a slightly greater percentage of forested land existed within riparian zones than was observed within the overall watershed (Fig. 2).

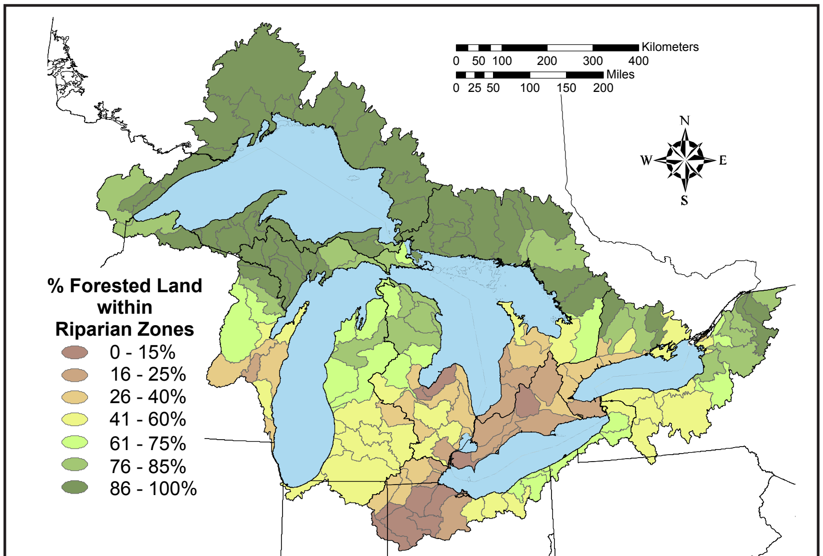

Figure 1. Percent Forested Land within Riparian Zones by Watershed in the Great Lakes Basin.
Upper St. Lawrence data are only presented for the U.S.
Sources: USDA Forest Service, Northeastern Area State and Private Forestry, Office of Knowledge Management and Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

Basin	U.S. (2001)		Ontario (2002)	
	% Forested (Entire Watershed)	% Forested (Riparian Areas)	% Forested (Entire Watershed)	% Forested (Riparian Areas)
Lake Superior	86.42%	88%	98.60%	98.05%
Lake Michigan	49.41%	63%		
Lake Huron	50.54%	52%	74.65%	77.04%
Lake Erie	21.20%	35%	14.30%	19.95%
Lake Ontario	47.30%	59%	49.99%	59.28%
St. Lawrence River	81.42%	83%		
Totals	50.77%	59.61%	73.05%	75.67%

Table 1. Percent of Land Forested within U.S. and Canadian Great Lakes Watersheds and Riparian Zones by Lake Basin.
Note: Upper St. Lawrence watersheds are not included with Canadian data.
Sources: USDA Forest Service, Northeastern Area State and Private Forestry, Office of Knowledge Management and Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

While good water quality is generally associated with heavily forested or undisturbed watersheds, (USDA 2004) the existence of a forested buffer near surface water features can also protect soil and water resources despite the land use class present in the rest of the watershed (Carpenter *et. al* 2003). As the percentage of forest coverage within a riparian zones increases, the amount of runoff and erosion (and therefore nutrient loadings, non-point source pollution and sedimentation) decreases, and the capacity of the ecosystem to store water increases. Studies show that heavy forest cover is capable of reducing total runoff by as much as 26% as compared to treeless areas with equivalent land-use conditions (Sedell *et. al* 2000) and that riparian forests can reduce nutrient and sediment loadings by 30 to 90% (Alliance for the Chesapeake Bay 2004).

Biodiversity of aquatic species is further maintained in riparian areas with increased forest coverage by an increase in the amount of large woody debris (which affects stream configuration, regulation of organic matter and sediment storage, and aquatic habitat availability) and decreased water temperatures (Eubanks et. al 2002). A study completed in Pennsylvania in 1985 claimed that complete commercial clear cutting of a riparian zone allowed a 10˚C (18˚F) rise in stream water temperatures, but the retention of a forested buffer strip only allowed an increase of about 1˚C (1.8˚F) (Binkley and MacDonald 1994). This regulation of water temperatures can be critical to the maintenance of assorted cold-water fish populations, e.g., trout.

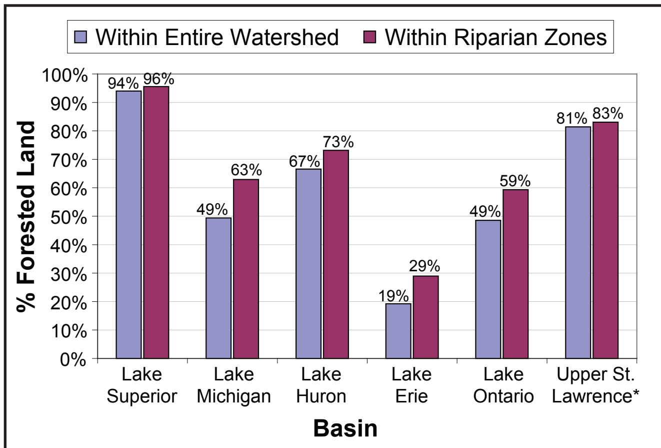

Figure 2. Percent of Land Forested within Great Lakes Watersheds and Riparian Zones by Lake Basin.
* = Upper St. Lawrence data only available for U.S.
Sources: USDA Forest Service, Northeastern Area State and Private Forestry, Office of Knowledge Management and Ontario Ministry of Natural Resources, Forest Standards and Evaluation Section.

The lack of consensus on the desired percentage of forested land in the basin or riparian zone (and the desired size of the riparian zone itself) makes it difficult to determine the specific implications of the presented data. Comparisons to historical forest cover in riparian zones and manipulative experiments would be useful for trend establishment.

<u>Component (2): Change in area of forest lands certified under sustainable forestry programs in Great Lakes states and Ontario</u>
Sustainable forestry certification programs are designed to ensure timber can be grown and harvested in ways that protect the local ecosystem. Participation is often voluntary, but once certification is gained, compliance with management protocols is required. Data from the Sustainable Forestry Initiative (SFI®), American Tree Farm System (ATFS), the Canadian Standards Association (CSA), and the Forest Stewardship Council (FSC) certification systems were analyzed for this report. The SFI is a voluntary forest certification program that promotes sustainable forest management in North America and responsible procurement globally. The ATFS is geared towards non-industrial, private landowners, and its mission is "to promote the growing of renewable forest resources on private lands while protecting environmental benefits and increasing public understanding of all benefits of productive forestry" (American Forest Foundation 2004). The sustainable forest management standard operated thru CSA includes fulfillment of requirements at the local forest level, including public participation and adherence with the Canadian Council of Forest Ministers' (CCFM) set of Sustainable Forest Management criteria. The Forest Stewardship Council (FSC) is an international body that accredits certification organizations and guarantees their authenticity.

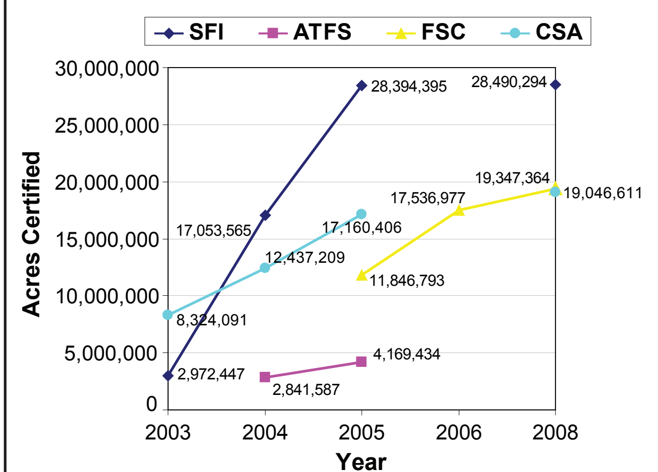

Figure 3. Trends in Forest Lands Certified Under SFI, ATFS, FSC, and CSA in the Great Lakes Region*.
* = Data for SFI and FSC are from U.S. Great Lakes states and the province of Ontario. Data for ATFS are only from U.S. Great Lakes states. Data for CSA are only from Ontario's Crown Lands.
Sources: Sustainable Forestry Initiative, American Tree Farm System (ATFS), Program Statistics and Forest Stewardship Council (FSC), Canadian Standards Association (CSA), Metafore Database.

The acres certified under each program are not additive, because one area of land can be certified with more than one system at a time. It is still important to note that an increasing trend is evident in every certification system during the last several years in Great Lakes states and the province of Ontario (Fig. 3). Additionally, forest landowners who only elect to enroll in the Sustainable Forestry Initiative (SFI®) program, but not go through the formal certification process, often choose to follow the forest management protocols but are not required to do so until they seek certification. It is therefore possible that a much greater amount of forest lands are being managed according to these sustainable practices than are represented by the given data.

These increases in the amount of certified forest lands can be interpreted as a greater commitment to sustainable forest management amongst forest industry professionals. Although data according to geographic coverage would be more useful for assessment purposes, it is obvious that progress has been made overall. The assumption is that continued growth in sustainable management practices will lead to improved soil and water resources in the areas where they are implemented.

Pressures

Component (1)

The same pressures exerted on all forest resources also apply here. Development of forest lands to other land use classes (such as developed, agricultural, or pasture) decreases the amount of forest area across watersheds and in riparian zones. Urbanization and seasonal home construction can specifically impact riparian areas since they are among the most desirable development locations.

Component (2)

Participation in sustainable forestry programs can be affected by marketplace popularity. Political climate, status of the economy, and public opinion can all influence forest managers decisions to gain certification.

Management Implications

Component (1)

The amount of non-forested area in riparian zones due to conversion to other land uses is a major issue that could be addressed with the development of policy directed towards increasing the area of forested lands in these zones. This active management approach to enhance forested buffers near surface waters could lead to possible improvements in local ecosystem health regardless of the land use classification in the rest of the watershed.

Component (2)

Increased reporting of certification data according to extent of geographical coverage would make corresponding analyses easier. Greater participation in sustainable forestry certification programs would ensure that all timberland is managed in a sustainable manner.

Comments from the author(s)

Component (1)

For the purposes of this report, riparian zone was defined as 30 meters (98 ft) on each side of a surface water feature. Research shows that a forested buffer of this size achieves the widest range of water quality objectives, (Alliance for the Chesapeake Bay, 2004), and is a standard value often used by the USDA Forest Service, Northeastern Area State and Private Forestry. Other sources quote different amounts of forested buffer needed near surface water features to achieve the highest level of soil and water resources protection, ranging anywhere from 8 to 150 meters (26 to 492 feet) from the water's edge (Illinois Department of Natural Resources *et al*. 2000, Indiana Department of Natural Resources 2006, Ohio Department of Natural Resources 2006). The ideal riparian zone size can be affected by a variety of factors such as stream characteristics, vegetation and soil type, geomorphology, slope of land, and season (Eubanks *et. al*. 2002).

The resolution of the United States landcover dataset used in this analysis was coarse enough to cause slight inaccuracies, but the data were determined as suitable for summarization at the watershed scale.

Additional research of existing literature would be helpful in further quantifying the effects of riparian forests on erosion, run-off, water temperatures, and nutrient and pollutant storage. Although specific studies have been done on these topics, the differences in metrics and sample locations complicate comparisons for the Great Lakes basin.

Component (2)

Subsequent analyses would be improved if data were collected for the percent of forested riparian zones that lie within areas certified by sustainable forestry programs. Presently, certification data cannot be analyzed geospatially by watershed or riparian area, therefore analyses are restricted to assessments of changing trends in the programs' utilization. It is unlikely that U.S. spatial data for certified lands will be available in the near future.

Expanding this component to include the amount of non-forested area in riparian zones due to conversion to other land uses and rates of compliance with Forestry Best Management Practices (BMPs) would provide valuable information for additional analyses. While certification in sustainable forestry programs often includes the implementation of BMPs, not all forest lands managed according to BMPs are also certified. Forestry BMPs have been developed in all Great Lakes states and provinces, so obtaining the relevant audit data would provide a greater and more detailed information base relating to the conservation of forest, soil and water resources.

Many BMPs are directed at reducing non-point source pollution, and some states even have monitoring data relating to issues such as water quality. For example, Wisconsin's Forestry Best Management Practices for Water Quality report stated that, when BMPs were correctly applied to areas where they were needed, 96% of the monitored area showed no adverse impact on water quality (Breunig *et al*. 2003). It is generally accepted that this trend exists in other states as well. For although individual states' BMPs may differ, studies have shown that their correct implementation results in effective protection of water quality overall.

Assessing Data Quality

Component (1)

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes: Data should be used for planning purposes only, as they may not reflect what is actually on the ground.						

Component (2)

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin				X		
5. Data obtained from sources within the U.S. are comparable to those from Canada				X		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes: United States data include all lands certified by the noted sustainable forestry programs in the states (not just the lands within the Great Lakes Basin). The Sustainable Forestry Initiative is the only certification scheme where comparable data are included for both U.S. and Canadian lands.						

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Last Updated
State of the Great Lakes 2009

Acid Rain

Indicator #9000

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Note: *The Acid Rain Indicator Report was drafted in the fall of 2008 using data that were available at that time. Since then, a number of Canadian and U.S. governmental reports have been released with more up-to-date information. These reports include the United States-Canada Air Quality Agreement: 2008 Progress Report and the 2006/2007 Progress Report on The Canada-Wide Acid Rain Strategy for Post-2000. The information and data presented in these reports (and others) will be incorporated into the 2012 State of the Great Lakes Acid Rain Indicator Report.*

Lake-by-lake Assessment

Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To assess the levels of sulphate and nitrate in precipitation in the Great Lakes basin.
- To assess the area within the Great Lakes basin in exceedance of critical loads of sulphate and nitrate to aquatic and terrestrial ecosystems measured as amount of total deposition (sulphate and nitrate) above the critical load (equivalents per hectare per year or eq/ha/yr).
- To infer the efficacy of policies to reduce sulphur and nitrogen acidic compounds released into the atmosphere.

Ecosystem Objective

This indicator supports:

- Both the Acid Rain Annex and the Ozone Annex of the 1991 United States-Canada Air Quality Agreement (Air Quality Agreement), which was established to address the transboundary flow of air pollution between the two countries. With respect to acid rain, the Air Quality Agreement sets specific sulphur dioxide (SO_2) and nitrogen oxide (NO_X) reduction targets and establishes a forum for acid rain related scientific and technical cooperation.
- Annexes 1 and 15 of the 1978 Great Lakes Water Quality Agreement.
- The Canada-Wide Acid Rain Strategy for Post-2000, Canada's principle domestic policy tool for managing acid rain, (http://www.ccme.ca/assets/pdf/1998_acid_rain_strategy_e.pdf), the long-term goal of which is "to meet the environmental threshold of critical loads for acid deposition across Canada", i.e., to ensure that no areas of Canada are receiving levels of acid deposition above which damage may occur.

State of the Ecosystem

Background

Acid rain, or "acid deposition," is caused when two common air pollutants, (SO_2) and (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 United States). 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 report published by the Hubbard Brook Research Foundation demonstrated that acid deposition is still a significant problem and has had a greater environmental impact than previously thought (Driscoll *et al*. 2001). For example, acid deposition has altered soils in the Northeastern United States through the accelerated leaching of base cations, the accumulation of nitrogen and sulphur, and an increase in concentrations of aluminum in soil waters. Acid deposition has also contributed to the decline of red spruce (*Picea rubens*) trees and sugar maple (*Acer saccharum*) trees in the Eastern United States. 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.

<u>Sulphur Dioxide and Nitrous Oxides Emissions Reductions</u>

SO_2 emissions come from a variety of sources. The largest source of SO_2 emissions in Canada continues to be the non-ferrous mining and smelting industry, although other industrial sources and electric power generation are also significant. In the United States, electric power generation constitutes the largest emissions source of SO_2 (Fig. 1). Mobile (or transportation) sources are the primary source of NO_X emissions in both countries, with electric utilities and industrial sources also contributing substantially (Fig. 2).

Under The Canada-Wide Acid Rain Strategy for Post-2000, Canada is committed to reducing acid deposition 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. Canadian SO_2 emissions in 2006 totaled under 2 million tonnes (Mt), which is 38% below the 3.2 Mt/yr national cap first defined in the 1985 First UN-Economic Commission Europe (UN-ECE) Sulphur Protocol (cap for 1993 and beyond) and reiterated under the United States-Canada Air Quality Agreement (cap for 2000 and beyond). The seven easternmost provinces’ ~1.3 Mt of SO_2 emissions in 2006 were more than 40% below the cap of 2.3 million Mt/yr, set by the former Eastern Canada Acid Rain Program.

In 2006, all participating sources of the U.S. Environmental Protection Agency’s (U.S. EPA) Acid Rain Program (Phase I & II) fell below 10 million tons for the first time. The Acid Rain Program has now achieved a reduction in SO_2 emissions of more than 6.3 million tons, or about 40% of 1990 levels. The Acid Rain Program now affects approximately 3,500 electric generating units. These units reduced their SO_2 emissions to 9.4 million tons in 2006, about 8% lower than 2005 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 and a 43% reduction from 1990 levels.

Canadian NO_X emissions in 2006 totaled 2.3 Mt, excluding open and natural sources, which represents a slight decrease nationally

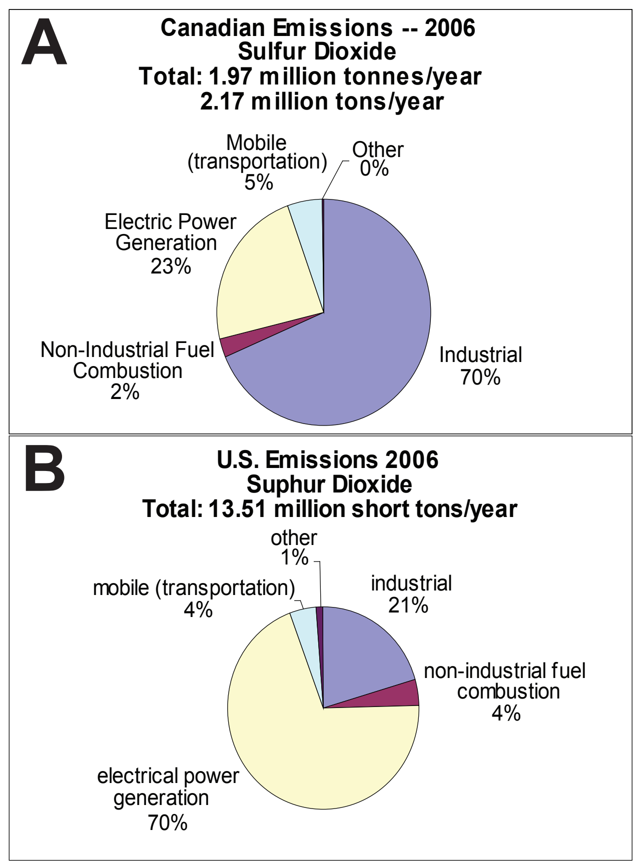

Figure 1. Sources of Sulphur Dioxide Emissions in Canada and the United States (2006).
Source: Environment Canada, 2008a. CAC Emission Trends (1985-2006) v2 (April 2008). http://www.ec.gc.ca/pdb/cac/Emissions1990-2015/xls/CAC_v2008_e.xls, last accessed September 17, 2008; and U.S. Environmental Protection Agency (USEPA). 2008a. National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data., last accessed September 19, 2008.

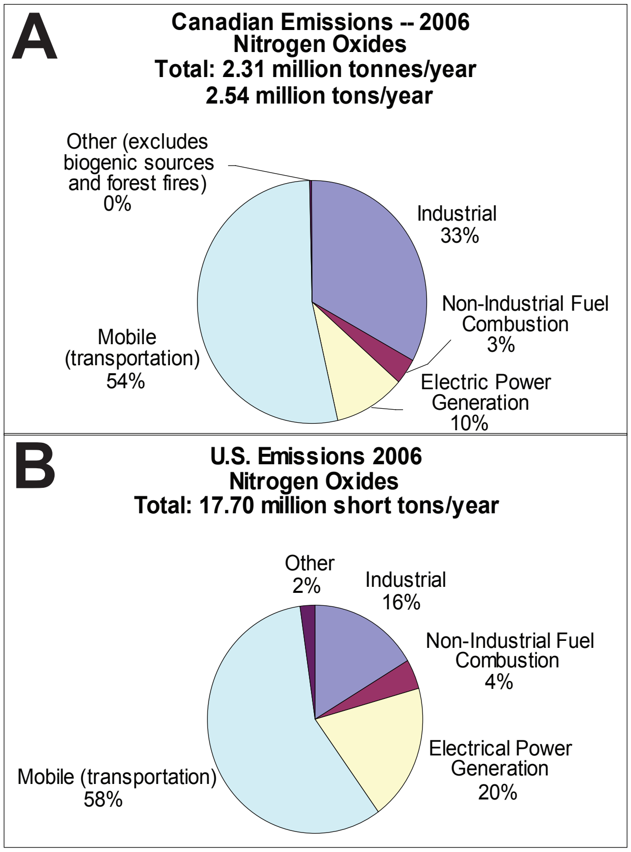

Figure 2. Sources of Nitrogen Oxides Emissions in Canada and the United States (2006).
Source: Environment Canada, 2008a. CAC Emission Trends (1985-2006) v2 (April 2008). http://www.ec.gc.ca/pdb/cac/Emissions1990-2015/xls/CAC_v2008_e.xls. Accessed on September 17, 2008; and U.S. Environmental Protection Agency (USEPA). 2008a. National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data., Accessed on September 19, 2008.

from 1990 emissions levels. NO_X emissions have remained relatively stable nationally over time due to emission increases in Western Canada being balanced out by reductions in Eastern Canada.

In the United States, 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 2006 were 3.4 million tons, about 49% lower than emissions from these sources in 1990 and about 6% lower than 2005 emissions. While the Acid Rain Program was responsible for a large portion of these annual NO_X reductions, other programs – including the Ozone Transport Commission, NO_X Budget Trading Program under EPA's NO_X State Implementation Plan (SIP) Call, and other regional NO_X emission control programs – also contributed significantly to the NO_X reduction achieved by sources in 2006.

Further information on SO_2 and NO_X emissions can be found in the Air Quality indicator report (#4202).

Deposition of Sulphates and Nitrates
Figure 3 compares wet sulphate deposition and wet nitrate deposition (kilograms per hectare per year or kg/ha/yr) over North America between two separate year periods, 1990-1994 and 2000-2004. Focusing on Eastern North America where both sulphate and wet nitrate deposition continue to be highest, a considerable difference can be observed in wet sulphate levels between the 1990-1994 and 2000-2004 average periods. For example, the large area that received 25 to 30 kg/ha/yr of sulphate wet deposition in the 1990-1994 period had almost disappeared in the 2000-2004 period. This significant reduction in wet sulphate deposition can be directly attributed to reduced SO_2 emission reductions in both countries from the early 1990s to the early 2000s. However, SO_2 emissions have remained relatively constant since the year 2000 therefore, it is unlikely that sulphate deposition will change considerably in the coming decade. Sulphate deposition models predict that even by 2020, following the achievement of commitments under the United States-Canada Air Quality Agreement and The Canada-Wide Acid Rain Strategy for Post 2000, critical loads for aquatic ecosystems in eastern Canada will continue to be exceeded over a large area.

A somewhat different story occurs for nitrate wet deposition with reductions being more modest between the two periods than in the case of sulphate. In the case of wet nitrate deposition, the highest deposition occurs around the lower Great Lakes. The choice was made to map circles in Eastern Canada for the 2000-2004 year period, as opposed to contour lines, due to the paucity of data from some of the provinces for those particular years. This is due to a combination of provincial networks being shut down or delays in data submission. Efforts are being made to improve data availability for future deposition mapping exercises.

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 SO_2 emissions

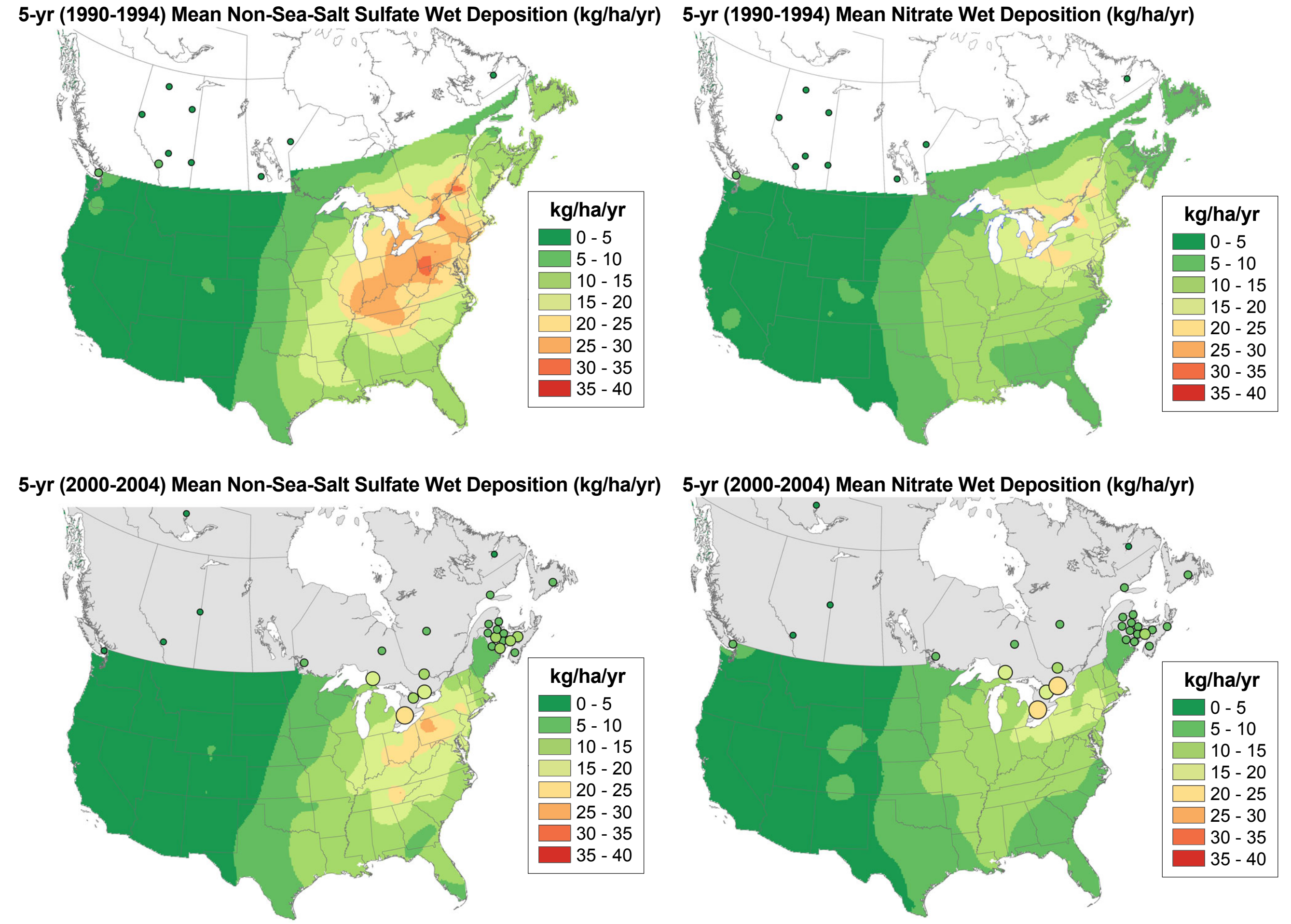

Figure 3. Five-year patterns of mean non-sea-salt-sulphate wet deposition (kg/ha/yr) and mean nitrate wet deposition for the periods 1990-1994 and 2000-2004.
Source: Figures 4, 5, 6 and 7 of the United States-Canada Air Quality Agreement: 2006 Progress Report. http://www.epa.gov/airmarkets/progsregs/usca/docs/2006report.pdf or http://www.ec.gc.ca/cleanair-airpur/83930AC3-60EE-4A14-A241-A10A83D3B055/2006_can_us_en_low_res.pdf. Accessed on June 1, 2009.

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 United States-Canada 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 United States to aggressive emission reduction measures to reduce emissions of NO_X and volatile organic compounds. (For more information on ozone, refer to Air Quality indicator report #4202).

On March 10, 2005, the U.S. EPA issued the Clean Air Interstate Rule (CAIR), a cap-and-trade approach that would permanently cap emissions of SO_2 and NO_X across 28 Eastern states and the District of Columbia. When fully implemented, CAIR was expected to significantly reduce SO_2 and NO_X emissions in these states. In July 2008, however, a U.S. federal appeals court panel vacated CAIR. The U.S. EPA is reviewing the Court's decisions and evaluating its impacts.

The 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 former emissions caps set under the Eastern Canada Acid Rain Program. Quebec, New Brunswick and Nova Scotia are committed to achieving their caps by 2010, while Ontario committed to meet its new cap by 2015.

Comments from the author(s)
While North American SO_2 emissions and sulphate 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 sulphur, 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.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

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Last updated
State of the Great Lakes 2009

Non-native Species – Aquatic

Indicator #9002

Overall Assessment

Status: **Poor**
Trend: **Deteriorating**
Rationale: **Nonindigenous species (NIS) continue to be discovered in the Great Lakes. Negative impacts of established invaders persist and new negative impacts, including synergistic disruptions, are becoming evident.**

Lake-by-Lake Assessment

Lake Superior
Status: Fair
Trend: Unchanging
Rationale: Lake Superior is the site of most ballast water discharge in the Great Lakes, but it supports relatively few NIS. This is due at least in part to less hospitable environmental conditions.

Lake Michigan
Status: Poor
Trend: Deteriorating
Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations are declining.

Lake Huron
Status: Poor
Trend: Deteriorating
Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations are declining.

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: Established invaders continue to exert negative impacts on native species. A possible link exists between waterfowl deaths due to botulism and established NIS (i.e., round goby and dreissenid mussels). An introduced virus (Viral Hemorrhagic Septicemia (VHS)) has caused mass die-offs of fish. *Diporeia* have become extirpated.

Lake Ontario
Status: Poor
Trend: Deteriorating
Rationale: Native *Diporeia* populations are declining in association with quagga mussel expansion. Condition and growth of lake whitefish, whose primary food source is *Diporeia*, are declining. A possible link exists between waterfowl deaths due to botulism and established NIS (i.e., round goby and dreissenid mussels). An introduced virus (VHS) has caused mass die-offs of fish.

Purpose

- To assess the presence, number and distribution of nonindigenous species (NIS) in the Laurentian Great Lakes
- 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 United States 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 (United States and Canada 1987). Minimally, extinctions and unauthorized introductions must be prevented to maintain biological integrity.

State of the Ecosystem

Background

At least 10% of NIS introduced to the Great Lakes have had significant impacts on ecosystem health, a percentage consistent with findings in the United Kingdom (Williamson and Brown 1986) and in the Hudson River of North America (Mills *et al.* 1997). In the Great Lakes, transoceanic ships are the primary invasion vector. Other vectors, such as canals and private sector activities (e.g., aquarium and bait industries), however, may play increasingly important roles.

Status of NIS

Human activities associated with transoceanic shipping are responsible for over one-third of NIS introductions to the Great Lakes (Fig. 1). Total numbers of NIS introduced and established in the Great Lakes have increased steadily since the 1830s (Fig. 2a). The numbers of ship-introduced NIS, however, has increased exponentially during the same time period (Fig. 2b). Release of contaminated ballast water by transoceanic ships has been implicated in over 60% of faunal NIS introductions to the Great Lakes since the opening of the St. Lawrence Seaway in 1959 (Grigorovich *et al.* 2003; Ricciardi 2006).

During the 1980s, the importance of ship ballast water as a vector for NIS introductions was recognized, finally prompting ballast management measures in the Great Lakes. In the wake of Eurasian ruffe and zebra mussel introductions, Canada introduced voluntary ballast exchange guidelines in 1989 for ships declaring "ballast on board" (BOB) following transoceanic voyages, as recommended by the Great Lakes Fishery Commission and the International Joint Commission. In 1990, the United States Congress passed the Nonindigenous Aquatic Nuisance Prevention and Control Act, producing the Great Lakes' first ballast exchange and management regulations in May of 1993. The National Invasive Species Act (NISA) followed in 1996, but this act expired in 2002. A stronger version of NISA entitled the Nonindigenous Aquatic Invasive Species Act has been drafted and awaits Congressional reauthorization.

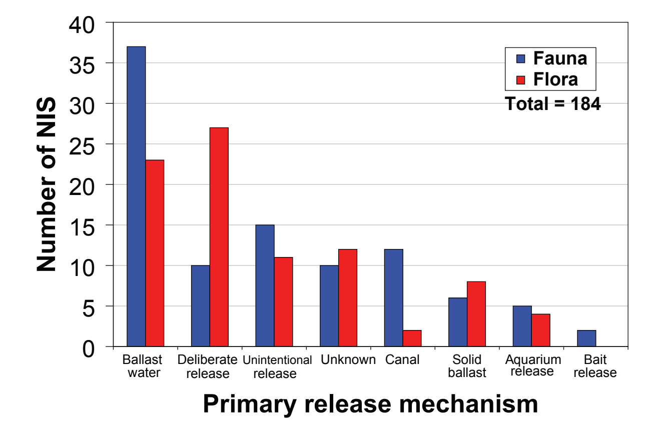

Figure 1. Release mechanisms for aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1840s. Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003; Ricciardi 2006.

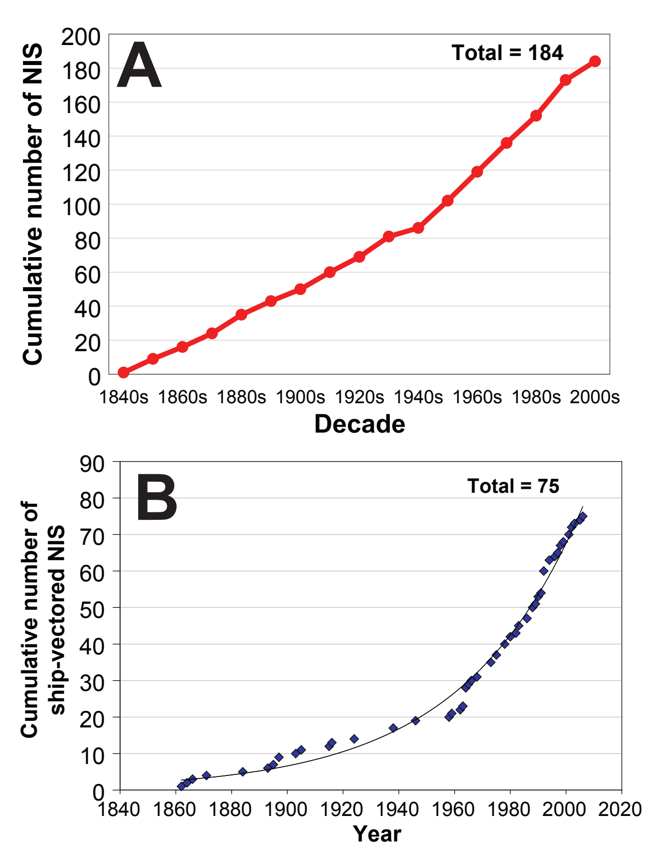

Figure 2. Cumulative number of aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1840s attributed to (a) all vectors and (b) only the ship vector. Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003; Ricciardi 2006.

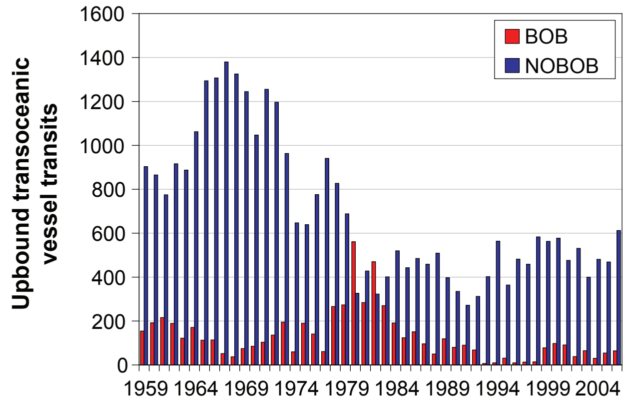

Figure 3. Numbers of upbound transoceanic ballasted (BOB) and cargo laden (NOBOB) vessels entering the Great Lakes from 1959 to 2006.
Source: Colautti *et al.* 2003; Grigorovich *et al.* 2003; Holeck *et al.* 2004; Saint Lawrence Seaway Development Corporation Annual Traffic Reports, http://www.greatlakes-seaway.com/en/seaway/facts/traffic/index.html.

Contrary to expectations, the reported invasion rate has not declined following initiation of voluntary guidelines in 1989 and mandated regulations in 1993 (Grigorovich *et al.* 2003, Holeck *et al.* 2004; Ricciardi 2006). However, more than 90% of transoceanic ships that entered the Great Lakes during the 1990s declared "no ballast on board" (NOBOB, Colautti *et al.* 2003, Grigorovich *et al.* 2003, Holeck *et al.* 2004, Fig. 3) and were not required to exchange ballast, although their tanks contained residual sediments and water that would be discharged in the Great Lakes. The residual waters and sediments of these ships have been found to contain several species previously unrecorded in the basin, and such species could be discharged after the ship undergoes sequential ballasting operations as it travels between ports within the Great Lakes to offload and take on cargo (Duggan *et al.* 2005, Ricciardi and MacIsaac 2008). In 2006, Canada implemented new regulations for the management of residuals contained within NOBOB tanks, and requires the salinity of all incoming ballast water to be at least 30 ppt (Government of Canada 2006).

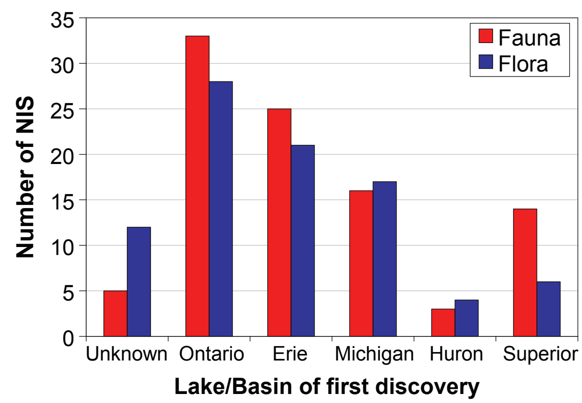

Figure 4. Lake of first discovery for NIS established in the Great Lakes basin since the 1840s.
Discoveries in connecting waters between Lakes Huron, Erie and Ontario were assigned to the downstream lake.
Species that were widespread at the time of discovery were assigned to the unknown category.
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/ncrais/glansis.html.

Recent studies suggest that each of the Great Lakes may differ in vulnerability to invasion. Lake Superior receives a disproportionately high number of discharges by both BOB and NOBOB ships, yet it has sustained surprisingly few initial invasions (Fig. 4). Conversely, the waters connecting Lake Huron and Lake Erie are an invasion 'hotspot' despite receiving disproportionately few ballast discharges (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 United States fish farms have been sighted below an electric dispersal barrier in the Chicago Sanitary and Ship Canal, which connects the Mississippi River and Lake Michigan. The prototype barrier was activated in April 2002 to block the transmigration of species between the Mississippi River system and the Great Lakes basin. The U.S. Army Corps of Engineers (partnered by the State of Illinois) completed construction of a second, permanent barrier in 2005.

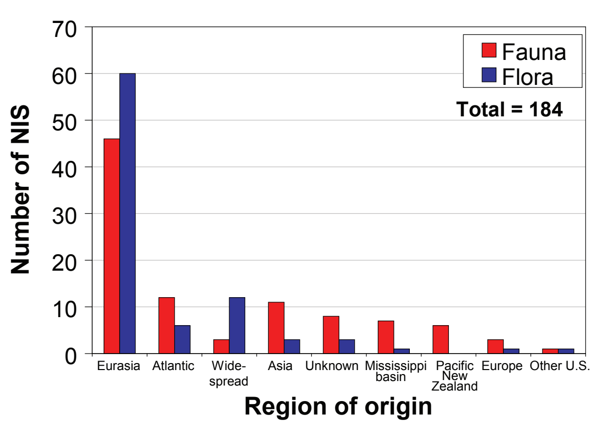

Figure 5. Regions of origin for aquatic NIS established in the Great Lakes basin since the 1840s.
Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003; Ricciardi 2006.

Second only to shipping, unauthorized release, transfer, and escape have introduced NIS into the Great Lakes. Of particular concern are private sector activities related to aquaria, garden ponds, baitfish, and live food fish markets. For example, nearly

Species	Reference
Fishes	
Aphanius (Atherina) 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. **Hemimysis anomala* was discovered in Lakes Ontario and Michigan in 2006.
Source: Ricciardi and Rasmussen 1998; Kolar and Lodge 2002; Grigorovich *et al.* 2003; Stokstad 2003; Rixon *et al.* 2005.

a million Asian carp, including bighead and black carp, are sold annually at fish markets within the Great Lakes basin. Until recently, most of these fish were sold live. All eight Great Lakes states and the province of Ontario now have some restriction on the sale of live Asian carp. Enforcement of many private transactions, however, remains a challenge. The U.S. Fish and Wildlife Service is considering listing several Asian carp as nuisance species under the Lacey Act, which would prohibit interstate transport. Finally, there are currently numerous shortcomings in legal safeguards relating to commerce in exotic live fish as identified by Alexander (2003) in Great Lakes and Mississippi River states, Quebec, and Ontario. These include: express and *de facto* exemptions for the aquarium pet trade; *de facto* exemptions for the live food fish trade; inability to proactively enforce import bans; lack of inspections at aquaculture facilities; allowing aquaculture in public waters; inadequate triploidy (sterilization) requirements; failure to regulate species of concern, e.g., Asian carp; regulation through "dirty lists" only, e.g., banning known nuisance species; and failure to regulate transportation.

Pressures

NIS have invaded the Great Lakes basin from regions around the globe (Fig. 5), and increasing world trade and travel will elevate the risk that additional species (Table 1) will continue to gain access to the Great Lakes. Indeed, the arrival of *Hemimysis anomala* was predicted (Ricciardi and Rasmussen 1998). Existing connections between the Great Lakes watershed and systems outside the watershed, such as the Chicago Sanitary and Ship Canal, and growth of industries such as aquaculture, live food markets, and aquarium retail stores will also increase the risk that NIS will be introduced.

Changes in water quality, global climate change, and previous NIS introductions also may make the Great Lakes more hospitable for the arrival of new invaders. Evidence indicates that newly invading species may benefit from the presence of previously established invaders. That is, the presence of one NIS may facilitate the establishment or population growth of another (Ricciardi 2001). For example, the sea lamprey (*Petromyzon marinus*) may have created enemy-free space that facilitated the alewife's

(*Alosa pseudoharengus*) invasion, and the round goby (*Neogobius melanstomus*) and *Echinogammarus* (amphipod) have thrived in the presence of previously established zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*). 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, such as the crustacean *Echinogammarus* and the round goby. Evidence suggests that they have promoted the proliferation of other nuisance species, including native and exotic weeds and blue-green algae (Skubinna *et al*. 1995, Vanderploeg *et al*. 2001).

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 rate of invasion may increase if positive interactions involving established NIS or native species facilitate the establishment of new NIS. Ricciardi (2001) suggested that such a scenario of "invasional meltdown" is occurring in the Great Lakes, although Simberloff (2006) cautioned that most of these cases have not been proven. Moreover, each new invader can interact in unpredictable ways with previously established invaders, potentially creating synergistic impacts (Ricciardi 2001, 2005). For example, recurring outbreaks of avian botulism in the lower Great Lakes are thought to result from the effects of dreissenid mussels and round gobies, in which the mussels create environmental conditions that promote the pathogenic bacterium and the gobies transfer bacterial toxin from the mussels to higher levels of the food web.

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 unforeseen ecological disruptions.

Comments from the author(s)

Lake-by-lake assessments should include Lake St. Clair and connecting channels (Detroit River, St. Clair River). Species first discovered in these waters were assigned to Lake Erie for the purposes of this report.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes:						

Acknowledgments

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Last Updated
State of the Great Lakes 2009

Non-native Species – Terrestrial

Indicator #9002

Overall Assessment

Status: **Not Assessed**
Trend: **Undetermined**
Rationale: **Terrestrial non-indigenous species (NIS) are pervasive in the Great Lakes basin. Although not all introductions have an adverse effect on native habitats, those that do pose a considerable ecological, social, and economic burden. Historically, the Great Lakes basin has proven to be particularly vulnerable to NIS, mainly due to population, industrialization, and the high volume of transboundary movement of goods and people. Data are disorganized, inhibiting an adequate assessment of the status, trends, and impacts of NIS in the region.**

Lake-by-Lake Assessment

Assessments of individual lake basins are unavailable due to lack of monitoring data.

Purpose

- To evaluate the presence, number, and impact of terrestrial NIS in the Great Lakes basin
- To assess the biological integrity of the Great Lakes basin ecosystems

Ecosystem Objective

The ultimate goal of this indicator is to limit, or prevent, the unauthorized introduction of NIS, and to minimize their adverse affect in the Great Lakes basin. Such actions would assist in accomplishing one of the major objectives of U.S. and Canada Great Lakes Water Quality Agreement, which is to restore and maintain the biological integrity of the waters of the Great Lakes ecosystem (United States and Canada 1987).

State of the Ecosystem

Globalization, i.e., the movement of people and goods, has led to a dramatic increase in the number of terrestrial NIS that are transported from one country to another. As a result of its high population density and high-volume transportation of goods, the Great Lakes basin is very susceptible to the introduction of such invaders. Figure 1 depicts this steady increase in the number of terrestrial NIS introduced into the Great Lakes basin and the rate at which this has occurred, beginning in the 1900s. In addition, the degradation, fragmentation, and loss of native ecosystems have also made this region more vulnerable to these invaders, enabling them to become invasive (NIS or strains that become established in native communities or wild areas and replace native species). The introduction of NIS is considered to be one of the greatest threats to the biodiversity and natural resources of this region, second only to habitat destruction.

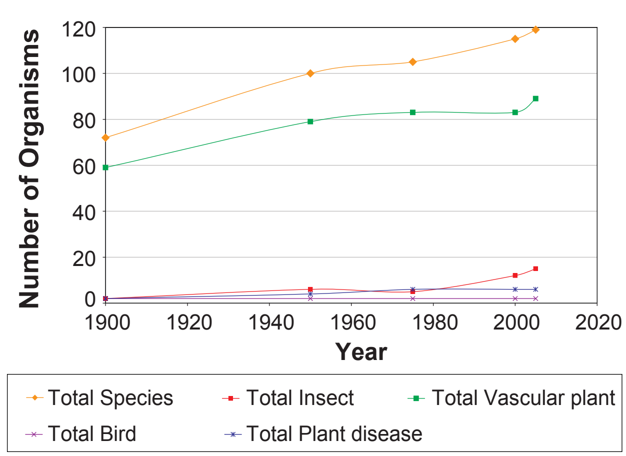

Figure 1. A timeline of terrestrial introduction in the Great Lakes basin by taxonomic group.
Source: World Wildlife Fund-Canada's Exotic Species Database, and the Canadian Food Inspection Agency

Monitoring of NIS is largely locally based, as a region-wide standard has yet to be established. The data that are generated come from a variety of agencies and organizations throughout the region, and they are difficult to use to assess the overall presence and impact these species are having on the region. Information provided by the World Wildlife Fund of Canada (WWF-Canada) (Haber 2003) indicates that there are 157 non-native terrestrial species located within the Great Lakes basin, including: 95 vascular plants, 11 insects, six plant diseases, four mammals, two birds, two animal diseases, one reptile, and one amphibian. Meanwhile, the Invasive Plant Association of Wisconsin (2003) has identified 66 non-native plants within the state, while over 100 plants have been introduced into the Chicago region (Chicago Botanic Garden 2007). Even though these figures are greater then the one provided by WWF-Canada, they do not compare to the over 900 non-native plants that have been identified within the state of Michigan by the Michigan Invasive Plant Council (2005).

The impact NIS have on the areas in which they are introduced can vary greatly, ranging from little or no affect to dramatically altering the native ecological community. Figure 2 shows the degree to which each taxonomic group has had an impact on the ecoregion. The WWF of Canada has listed 29 species, 19 of which are vascular plants, as having a "severe impact" on native biodiversity. These species, which were generally introduced for medicinal or ornamental purposes, have become problematic because they are well adapted to a broad range of habitats, have no native predators, and are often able to reproduce at a rapid rate. Common buckthorn (*Rhamnus cathartica*), garlic mustard (*Alliaria petiolata*), honeysuckle (*Lonicera japonica*), purple loosestrife (*Lythrum salicaria*), and reed canary grass (*Phalaris arundinacea*) are several examples of highly invasive plant species. The Asian longhorn beetle (*Anopolophora glabripennis*), Dutch elm disease (*Ophiostoma novo-ulmi* and *O. ulmi*), emerald ash borer (*Agrilus planipennis*), leafy spurge (*Euphorbia esula*), and the West Nile virus (*Flavivirus*) are other terrestrial invaders that have had a significant impact in the Great Lakes basin.

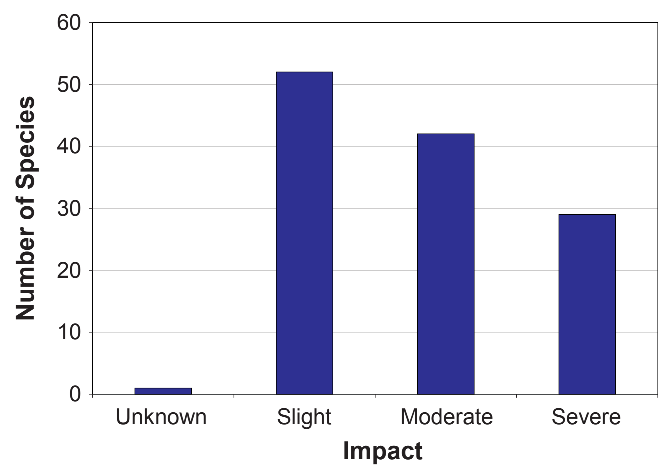

Figure 2. Estimated impact of 116 known terrestrial NIS in the Great Lakes basin.
Source: World Wildlife Fund-Canada's Exotic Species Database.

One type of terrestrial non-native species that is causing some concern is genetically modified organisms (GMOs). Although GMOs are typically cultivated for human uses and benefits, the problem arises when pollen is moved from its intended site (often by wind or pollinator species) and transfers genetically-engineered traits, such as herbicide resistance and pest resistance, to wild plants. This outward gene flow into natural habitats has the potential to significantly alter ecosystems and create scenarios that would pose enormous dilemmas for farmers. Both Canada and the United States are major producers of GMOs. Although GMO crops are monitored for outward gene flow, no centralized database currently exists that describes the number of GMO species or the land area covered by GMOs in the Great Lakes basin.

There are currently numerous policies, laws and regulations within the Great Lakes basin that address NIS. However, similar to NIS monitoring data, they originate from state, provincial and federal administrations and thus have similar obstacles associated with them. Strict enforcement of these laws, in addition to continuous region-wide mitigation, eradication and management of NIS, is needed in order to maintain the ecological integrity of the Great Lakes basin.

Pressures

The growing transboundary movement of goods and people has heightened the need to prevent and manage terrestrial NIS. Most invasive species introductions can be linked to the intended or unintended consequences of economic activities (Perrings *et al.* 2002). For this reason, the Great Lakes basin has been, and will continue to be, a hot bed of introductions unless preventive measures are enforced. The growth in population, threats, recreation and tourism all contribute to the number of NIS affecting the region. Additionally, factors such as the increase in development and human activity, previous introductions and climate change have elevated the levels of vulnerability. Because this issue has social, ecological, and economic dimensions, it can be assumed that the pressure of NIS will persist unless it is addressed on all three fronts.

Management Implications

Since the early 1800s, biological invasions have compromised the ecological integrity of the Great Lakes basin. Despite an elevated awareness of the issue and efforts to prevent and manage NIS in the Great Lakes, the area remains highly vulnerable to both intentional and non-intentional introductions. Political and social motivation to address this issue is driven not only by the effects on the structure and function of regional ecosystems, but also by the cumulative economic impact of invaders, i.e., threats to food supplies and human health.

Managers of terrestrial NIS in the Great Lakes basin recognize that successful management strategies must involve collaboration across federal, provincial and state governments, in addition to non-governmental organizations. Furthermore, improved integration, coordination and development of inventories, mapping, and mitigation of terrestrial invasive species would improve future strategies and enable the examination of trends in terrestrial NIS at a basin-wide scale.

In the United States, many organizations and activities have emerged in recent years to address invasive species issues. Their activities are numerous, but focus on four major areas: prevention (according to the National Invasive Species Council Management Plan (NISC 2001), the first line of defense against invasive species is to prevent them from becoming established); early detection and rapid response programs (which work in coordination with state and local efforts "to eradicate or contain invasive species before they became too widespread and control becomes technically and/or financially impossible"); ranking systems (which are designed to assess the relative threat posed by each invasive species in order to prioritize policy, management and education efforts); and regional or state plant councils (which include the NISC, Midwest Invasive Plant Network, Indiana Invasive Plant Species Assessment Working Group, Michigan Invasive Plant Council, Minnesota Invasive Species Advisory Council, Ohio Invasive Plants Council, Wisconsin Council on Invasive Species, and the Invasive Plants Association of Wisconsin). Binationally, the Invasive Species Council is also entering discussions with Environment Canada on the development of a North American approach to invasive alien species.

Environment Canada plays a coordinating role on the issue of non-native species working closely with other federal departments and agencies as well as provincial and territorial governments and stakeholders. Mirroring the U.S. NISC's objectives, Canada's *Invasive Alien Species Strategy* (Environment Canada 2004) prioritizes prevention, early detection, rapid response, and effective management through legislation and regulation, science, risk analysis, education and public awareness, and international cooperation. In 2005, the Canadian federal budget contained the first line item ever to target invasive species directly, for $85 million. Much of this funding was earmarked for battling the emerald ash borer and another forest pest, the Asian longhorn beetle, both which have infected hardwood trees in the basin.

Examples of ongoing Canadian multi-level responses within the basin include: Biodiversity Institute of Ontario- and University of Guelph-led Ontario Invasive Plant Information System (OIPIS), which was developed as a tool in the assessment, detection and prevention of invasive alien plants in Ontario; the Ontario Federation of Anglers and Hunters' and Ontario Ministry of Natural Resources' Invading Species Awareness Program; and the Environment Canada-led Monitoring the State of the St. Lawrence program, in partnership with Lake Saint-Pierre ZIP Committee, Société d'aménagement de la baie Lavallière, and Laval University, which utilizes community-based monitoring to track temporal and spatial trends in invasive plant species

Although current monitoring programs in the basin are fragmented, collaborative efforts are being developed to determine future monitoring priorities. This information will be applied to risk analysis, predictive science, modeling, improved technology for prevention and management of NIS, legislation and regulations, education and outreach and international co-operation.

Comments from the authors

In 2000 the WWF-Canada amassed information about 150 known NIS in Canada in a centralized database, based on books, journal articles, websites, and consultation with experts. The data also include information on NIS present in the U.S. portion of the Great Lakes basin. Currently, there is no central monitoring site for terrestrial NIS in the basin. The authors of the chapter acknowledge that a lack of centralized data was a limitation of the project. The information contained in this indicator is based on the WWF-Canada database and has been updated with several more recent insect invaders present in the Great Lakes basin.

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5.0 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	Department of Fisheries and Oceans Canada
EC	Environment Canada
ECO	Environmental Careers Organization
EERE	Office of Energy Efficiency and Renewable Energy (U.S. Department of Energy)
EIA	Energy Information Administration (U.S.)
EMAN	Ecological Monitoring and Assessment Network
FSC	Forest Stewardship Council
GERA	Gaia Economic Research Associates
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 (U.S. EPA)
HPMS	Highway Performance Monitoring System (U.S.)
IJC	International Joint Commission
IUCN	International Union for the Conservation of Nature
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
NAPS	National Air Pollution Surveillance (EC)
NHEERL	National Health & Environmental Effects Research Laboratory (U.S. EPA)
NISC	National Invasive Species Council
NOAA	National Oceanic and Atmospheric Administration
NRCan	Natural Resources Canada
NRCS	Natural Resources Conservation Service (USDA)
NRRI	Natural Resources Research Institute (University of Minnesota – Duluth)
NYSDEC	New York State Department of Environmental Conservation
ODNR	Ohio Department of Natural Resources
ODW	Ohio Division of Wildlife
OFEC	Ontario Farm Environmental Coalition
OGS	Ontario Geological Survey
OIPIS	Ontario Invasive Plant Information System
OMAF	Ontario Ministry of Agriculture and Food (now OMAFRA, see below)
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
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
REMAP	Regional Environmental Monitoring and Assessment Program (U.S.)
TNC	The Nature Conservancy
UKIH	United Kingdom Institute of Hydrology
USDA	U.S. Department of Agriculture
U.S. EPA	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
WWF	World Wildlife Fund (Canada)

Units of Measure

C	Celsius
cm	centimeter, 10^{-2} meters
F	Fahrenheit
fg	femptogram, 10^{-15} gram
ft	feet (English system)
ha	hectare, 10,000 square meters, 2.47 acres
lbs	pounds (English system)
kg	kilogram, 1000 grams, 2.2 pounds
km	kilometer, 0.62 miles
kt	English kiloton: $2*10^6$ pounds; metric kilotonne: 10^6 kg, $2.2*10^6$ pounds
kWh	kilowatt-hour
m	meter
mg	milligram, 10^{-3} gram
mg/kg	milligram per kilogram, part per million
mg/l	milligram per liter
ml	milliliter, 10^{-3} liter
mm	millimeter, 10^{-3} meter
MWh	megawatt-hour
ng	nanogram, 10^{-9} gram
ng/g	nanogram per gram, part per billion
ng/l	nanogram per liter
pg	picogram, 10^{-12} gram
pg/m^3	picogram per cubic meter
pH	per Hydrogen (a unit of acidity)
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/l	microgram per liter
µg/m^3	microgram per cubic meter
µm	micrometer, micron, 10^{-6} meter

Chemicals

2,4-D	2,4-dichlorophenoxyacetic acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
BaP	Benzo[α]pyrene
BDE	Brominated diphenyl ethers
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
Hg	Mercury
MeHg	Methylmercury
NAPH	Naphthalene
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O^3	Ozone
OC	Organochlorine
OCS	Octachlorostyrene
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	Perfluorooctanyl 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
TGM	Total gaseous mercury
TOC	Total organic carbon
TRS	Total reduced sulfur
VOC	Volatile organic compound

<u>Other</u>

AAQC	Ambient Air Quality Criterion (Ontario)
AFO	Animal Feeding Operation
AOC	Area of Concern
AOU	Area of the Undertaking
APF	Agricultural Policy Framework (Canada)
AQI	Air Quality Index
ARET	Accelerated Reduction/Elimination of Toxics program (Canada)
ATFS	American Tree Farm System
BA	Abnormal Barbels
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
BUI	Beneficial Use Impairments
CAFO	Concentrated Animal Feeding Operations
CAIR	Clean Air Interstate Rule
CBT	Caffeine Breath Test

C-CAP	Coastal Change and Analysis Program
CC/WQR	Consumer Confidence/Water Quality Report
CEPA	Canadian Environmental Protection Act
CFU	Colony Forming Units
CHT	Contaminants in Human Tissue program (part of EAGLE)
CMA	Census Metropolitan Area (Canada)
CNMP	Comprehensive Nutrient Management Plan (U.S.)
CSO	Combined Sewer Overflow
CUE	Catch per Unit of Effort
CUrLUS	Canadian Urban Land Use Survey
CWS	Canada-wide Standard (air quality)
DWS	Drinking Water System (Canada)
EAGLE	Effects on Aboriginals of the Great Lakes program (Canada)
DWSP	Drinking Water Surveillance Program (Canada)
EAPI	External Anomaly Prevalence Index
EFP	Environmental Farm Plan (Ontario)
EMS	Early Mortality Syndrome
EO	Element Occurrence
EPR	Extended Producer Responsibility
ESV	Early Successional Vegetation
FCGO	Fish Community Goals and Objectives
FCO	Fish Community Objectives
FD	Focal Discoloration
FIA	Forest Inventory and Analysis (USDA Forest Service)
FQI	Floristic Quality Index
GAP	Gap Analysis Program (land cover assessment)
GHG	Greenhouse Gases
GIS	Geographic Information System
GLEI	Great Lakes Environmental Indicators
GLI	Great Lakes Initiative (U.S. EPA)
GLWQA	Great Lakes Water Quality Agreement
GMO	Genetically Modified Organisms
HGEMP	Herring Gull Egg Monitoring Program
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
LE	Lesion
LEL	Lowest Effect Level
LU/LC	Land use/Land cover
MAC	Maximum Acceptable Concentration
MACT	Maximum Available Control Technology
MCL	Maximum Contaminant Level
MEI	Modified Environmental Index
MGD	Million Gallons per Day (3785.4 m^3 per day)
MLD	Million Liters per Day (1000 m^3 per day)
MMP	Marsh Monitoring Program
MSA	Metropolitan Statistical Area (U.S.)
MSWG	Municipal Solid Waste Generation

NAFTA	North America Free Trade Agreement
NATTS	National Air Toxics Trend Site (U.S. network)
NATA	National Air Toxics Assessment (U.S.)
NEEAR	National Epidemiological and Environmental Assessment of Recreational [Water Study]
NEI	National Emissions Inventory (U.S.)
NHANES	National Health and Nutrition Examination Survey (CDC)
NM Act	Nutrient Management Act
NMAN	Nutrient Management Planning software (Ontario)
NIS	Nonindigenous species
NISA	National Invasive Species Act
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)
NTU	Nephelometric Turbidity Units
ODWQS	Ontario Drinking Water Quality Standard
OPEP	Ontario Pesticides Education Program
PBT	Persistent Bioaccumulative Toxic (chemical)
PEL	Probable Effect Level
PICA	Priority Island Conservation Areas
PNP	Permit Nutrient Plans (U.S.)
PGMN	Provincial Groundwater-Monitoring Network (Ontario)
RAP	Remedial Action Plan
RfD	References Dose
RPA	Resource Planning Act
RG	Raised Growths
SDWIS	Safe Drinking Water Information System (U.S.)
SFI®	Sustainable Forestry Initiative
SIP	State Implementation Plan
SOLEC	State of the Lakes Ecosystem Conference
SOLRIS	Southern Ontario Land Resource Information System
SPP. or spp.	Species
SQI	Sediment Quality Index
SSO	Sanitary Sewer Overflow
SUV	Sport Utility Vehicle
SWMRS	Seasonal Water Monitoring and Reporting System (Canada)
TCC	Total Category Change
TCR	Total Coliform Rule
TDI	Tolerable Daily Intake
TEQ	Toxic Equivalent
TIGER	Topological Integrated Geographic Encoding and Reference (U.S. Census Bureau)
TM	Thematic Mapper
TRI	Toxics Release Inventory (U.S.)
UNECE	United Nations Economic Commission for Europe
VKT	Vehicle Kilometers Traveled
WIC	Women Infant and Child (Wisconsin health clinics)
WISCLAND	Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data
WTP	Water Treatment Plant
WWTP	Waster Water Treatment Plant
YOY	Young-of-year

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- Canadian Food Inspection Agency
  - Plant Pest Surveillance Unit
- Environment Canada
  - Canadian Wildlife Service
    - Ontario Region
    - Sustainable Water Management
  - Communications Branch
    - Program Advice and Support - Ontario
  - Environmental Stewardship Branch
    - Strategic Priorities
      - Air Emissions Priorities
      - Ecosystem and Biodiversity Priorities (formerly Biodiversity Convention Office)
    - Environmental Protection Operations Division – Ontario
      - Environmental Emergencies Section
      - Program Integration Section
  - Meteorological Service of Canada
  - Science and Technology Branch
    - Air Quality Research
      - Measurements & Analysis Research Section (formerly International Air Deposition Network)
      - Analysis and Air Quality Section (formerly National Air Pollution Surveillance Network)
    - Climate Research (formerly Climate and Atmospheric Research Directorate)
      - Climate Data and Analysis Section
    - Water Science and Technology (formerly National Water Research Institute)
      - Aquatic Ecosystem Impacts Research Division
      - Lake Management Research Division
      - Water Quality Monitoring and Surveillance (formerly Ecosystem Health Division)
    - Wildlife and Landscape Science
      - Landscape Science and Technology (formerly Ecological Monitoring and Assessment Network)

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Great Lakes Environmental Research Laboratory
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Canada Centre for Remote Sensing
Geomatics Canada
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Geological Survey of Canada
Canadian Forest Service
United States Army Corps of Engineers
Detroit District
Chicago District
United States Coast Guard
Ninth Coast Guard District
United States Department of Agriculture
Natural Resource Conservation Service
United States Forest Service
Northern Research Station
Forest Inventory and Analysis
Northeastern Area State and Private Forestry
United States Department of Health and Human Services
Center for Disease Control
Agency for Toxic Substances and Disease Registry
Research Implementation Branch
Federal Occupational Health
United States Department of Interior
National Park Service
Great Lakes Network Office
Sleeping Bear Dunes National Lakeshore
United States Environmental Protection Agency
Great Lakes National Program Office
Office of Research and Development
National Health and Environmental Effects Research Laboratory
Mid-Continent Ecology Division
National Exposure Research Laboratory
Environmental Sciences Division
Landscape Ecology Branch
Region 2
Watershed Management Branch
New York Watershed Management Section
Region 5
Land and Chemicals Division

Office of Public Affairs
Water Division
Waste, Pesticides, and Toxics Division
United States Fish and Wildlife Service
Alpena National Fish and Wildlife Conservation Office
Ashland National Fish and Wildlife Conservation Office
Green Bay National Fish and Wildlife Conservation Office
La Crosse Fish Health Center
Lower Great Lakes Fishery Resource Office
United States Geological Survey
Biological Resources Division
Great Lakes Science Center
Lake Erie Biological Station
Lake Ontario Biological Station
Lake Superior Biological Station
National Wildlife Health Center
Water Resources Division

Provincial and State
Illinois Department of Natural Resources
Illinois Environmental Protection Agency
Division of Remediation Management
Indiana Department of Environmental Management
Natural Resources Damage Program
Indiana Department of Natural Resources
Indiana Finance Authority
Indiana Brownfields Program
Michigan Coastal Management Program
Michigan Department of Environmental Quality
Office of the Great Lakes
Remediation and Redevelopment
Michigan Department of Natural Resources
Minnesota Department of Natural Resources
Minnesota Pollution Control Agency
Environmental Indicators Unit
Voluntary Investigation and Cleanup Unit
New York Department of Environmental Conservation
Cape Vincent Fisheries Research Station
Great Lakes Programs
Ohio Department of Natural Resources
Ohio Division of Wildlife
Sandusky Fish Research Unit
Ohio Environmental Protection Agency
Lake Erie Program
Voluntary Action Program
Ohio Lake Erie Office
Ontario Ministry of Agriculture Food and Rural Affairs
Ontario Ministry of Environment
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Water Monitoring and Reporting Section
Great Lakes Unit
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        Forests Management Branch
            Forest Evaluation and Standards Section
Natural Resource Management Division
        Fish and Wildlife Branch
            Biodiversity Section
        Great Lakes Branch
            Lake Erie Management Unit
Upper Great Lakes Management Unit
        Lands and Waters Branch
            Water Resources Section
    Ontario Natural Heritage Information Centre
Ontario Parks
Pennsylvania Department of Environmental Protection
    Great Lakes Office
    Land Recycling Program
Presque Isle State Park
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Wisconsin Department of Health and Family Services
Wisconsin Department of Natural Resources
    Division of Forestry
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City of Gary, Indiana, USA
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City of Hamilton, Ontario, Canada
City of Kitchener, Ontario, Canada
City of Kingston, New York, USA
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City of London, Ontario, Canada
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City of Mississauga, Ontario, Canada
City of Thunder Bay, Ontario, Canada
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    Human-Environment Modeling and Analysis Laboratory
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University of Wisconsin-Madison, Wisconsin, United States
    Department of Forest Ecology and Management
University of Wisconsin-Milwaukee, Wisconsin, United States
    Great Lakes WATER Institute
University of Wisconsin-Superior, Wisconsin, United States
    Lake Superior Research Institute

Partnerships
Ecological Monitoring and Assessment Network

Commissions
Great Lakes Commission
Great Lakes Coastal Wetland Consortium* no longer exists
Great Lakes Fishery Commission

Great Lakes Indian Fish & Wildlife Commission
International Joint Commission
    Great Lakes Regional Office

Environmental Non-Government Organizations
Bird Studies Canada
Grand River Conservation Authority
Great Lakes Forest Alliance
Great Lakes United
National Wildlife Federation
Nature Conservancy Canada
    Ontario Region
Northeast-Midwest Institute
    Great Lakes Cities Initiative
Northwest Michigan Council of Governments
Sustainable Forestry Initiative
The Nature Conservancy
    Great Lakes Program
World Wildlife Fund-Canada

Private Organizations
Bobolink Enterprises
Computer Sciences Corporation
Council of Great Lakes Industries
DynCorp
Environmental Affairs Consulting
Environmental Careers Organization* no longer exists
General Dynamics Advanced Information Systems
Habitat Solutions N.A.
LURA Consulting
National Council for Air and Stream Improvement, Inc.

Private Citizens