STATE OF THE GREAT LAKES

1. Introduction

1.1 Background to SOLEC

The Great Lakes represent the largest single reservoir of fresh water on the surface of the earth, excluding the polar ice caps. The Great Lakes basin ecosystem spans 9° of latitude and 19° of longitude, and lies halfway between the equator and the North Pole (Figure 1). The basin includes the Lakes themselves and over 760,000 square kilometers (295,000 square miles) of land that drains into them (Figure 2). The governments of Canada and of the United States of America have long recognized the value of the Great Lakes as an important natural resource and have worked cooperatively for decades to manage the Great Lakes ecosystem.

In 1995 the governments of the United States and of Canada, Parties to the Great Lakes Water Quality Agreement (GLWQA), released the first of a series of biennial State of the

Figure 1. Location of the Great Lakes Basin Ecosystem
Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

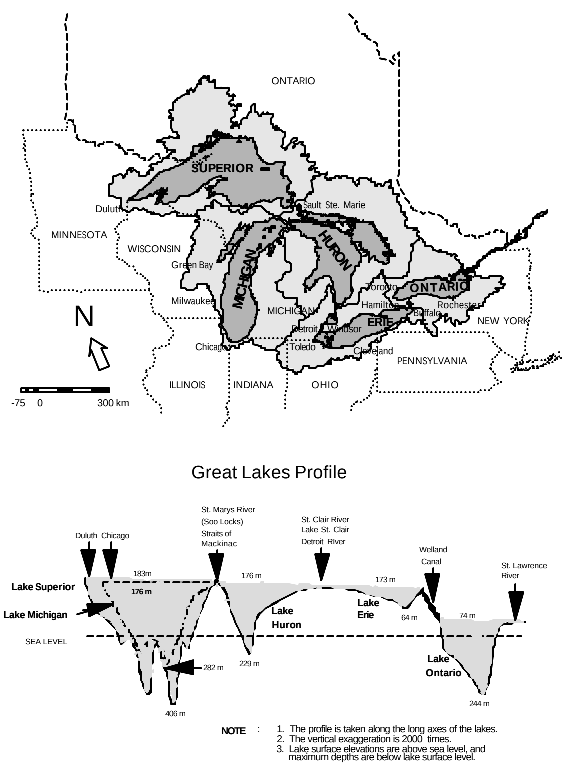

Figure 2. The Great Lakes Basin
Source: Environment Canada and U.S. Environmental Protection Agency. 1995. *State of the Great Lakes 1995.*

Great Lakes reports. It summarized the overall health of the Great Lakes ecosystem at the end of 1994. The 1997 State of the Great Lakes report, with its associated background papers, narrows the scope to summarize the condition of the nearshore ecosystem as observed at the end of 1996 and gives a limited update on the subjects addressed in the first report.

For both reports, information was gathered, discussed, and reviewed during one in a series of biennial conferences hosted by Environment Canada and the U.S. Environmental Protection Agency. These conferences are known as SOLEC (State of the Lakes Ecosystem Conference). The second conference, SOLEC 96, was held in November 1996 and provided a framework for this 1997 report.

The purpose of the conferences and the reports is to provide stakeholders, including policy-makers, throughout the basin with information to support better decisions on issues that will have an impact on the Great Lakes ecosystem. The conferences give stakeholders an opportunity to exchange their knowledge, experiences, and perspectives regarding the health of the ecosystem. The intent of the Parties is to deliver a binational science-based review of the state of the Great Lakes basin ecosystem, without assessing agency programs. The conferences and the reports also reflect the governments' ongoing commitment to improve their understanding of the complex ecological relationships that constitute the system. Accurately assessing the health of an ecosystem of this size depends on the cooperation of stakeholders throughout the basin.

Just as no single agency can accurately assess the health of such a large ecosystem, no single report can cover all the complexities of the Great Lakes ecosystem or include the vast amount of related information that is gathered every year. However, to provide structure for the conferences and the 1995 report, and to touch on as many aspects of the ecosystem as possible, the organizers used the three-level framework shown in Figure 3. We have continued using this framework for this report as well. The top level consists of the living components of the system, both the health of the human components and the health of the ecosystem. The middle level consists of the environmental aspects of the system, both supporting factors (positive) and stressors (negative). The lower level consists of the many sources of stressors. Programs to deal with problems in the system can be envisioned as another level, but are not included in these conferences or reports. Although programs are very important, they are a separate matter to be evaluated and discussed in other reporting vehicles of the Parties.

This report draws upon information from five background papers written for the 1996 conference:

Nearshore Waters of the Great Lakes
Coastal Wetlands of the Great Lakes
Land by the Lakes: Nearshore Terrestrial Ecosystems
Impacts of Changing Land Use
Information and Information Management

Land use is by far the largest source of stress in the system and warranted special attention. Additionally, a separate paper was prepared on information and information management because of their importance and the rapid changes in electronic data systems.

1.2 SOLEC 94

The first State of the Great Lakes report provided an overall view of the state of the Great Lakes ecosystem at the end of 1994 and drew the following conclusions:

- Loss of aquatic habitat has been devastating and has been largely ignored [up to that time] by government programs focused on contaminants.

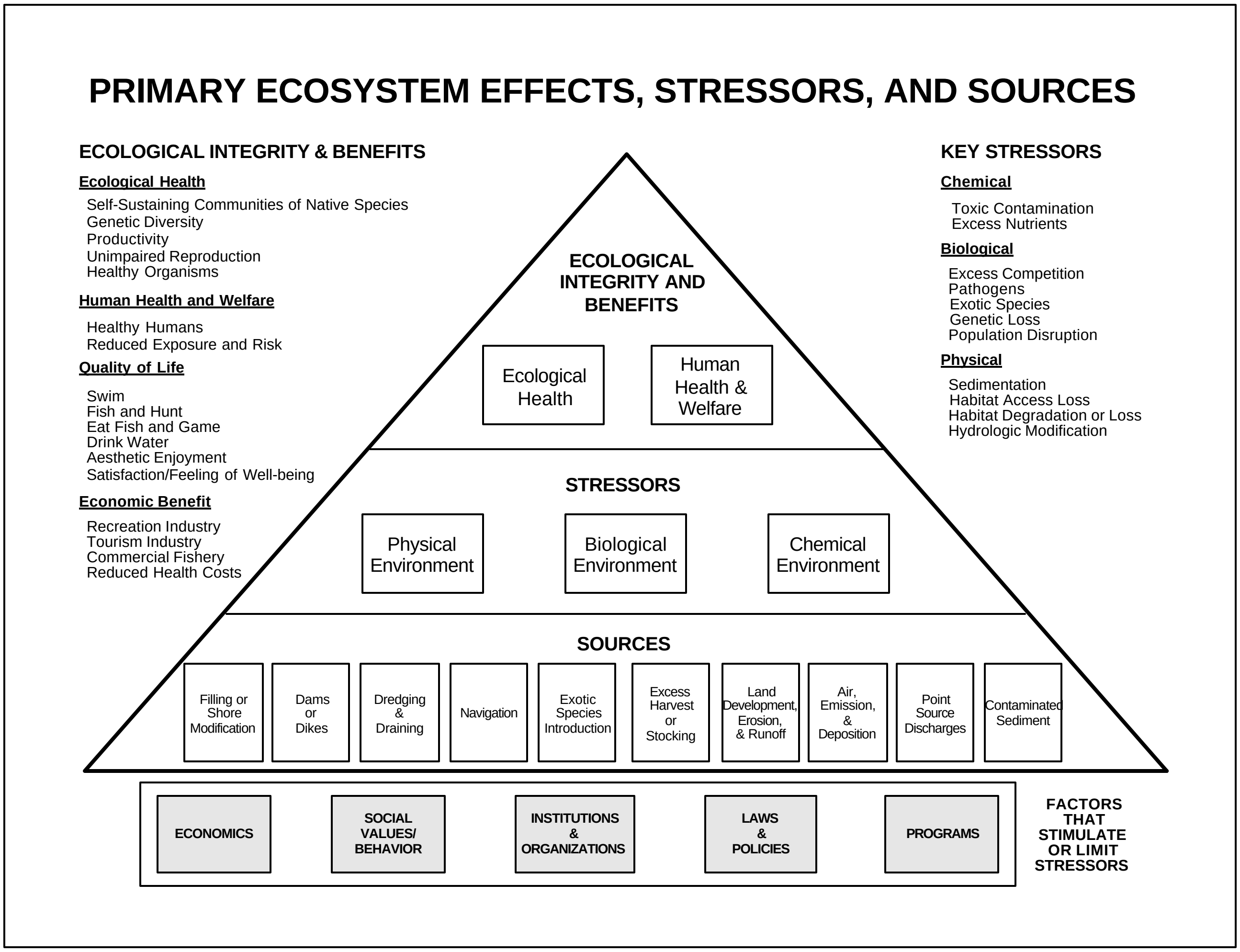

Figure 3. Conceptual Model of the Relationships Between Ecosystem Health, Stressors, and Sources of Stress
Source: Great Lakes National Programs Office, U.S. EPA

- Loss of native species has been equally devastating, with a collateral loss of biological diversity among and within the remaining species and populations.

- Invasions of non-native species have had major impacts on ecosystem integrity.

- Contaminant concentrations in fish and wildlife, as well as in sediments, have declined dramatically since the early 1970s, but are still a problem in some areas.

- The present phosphorus control strategies have attained targets.

- The health of humans living in the Great Lakes basin is no worse than the health of those living in other industrialized areas and is certainly better than in most countries in the world.

- Hormone disruption is an emerging issue that needs to be researched and monitored.

- There is a global component to contamination due to long-range atmospheric transportation and deposition of pollutants, which will make virtual elimination of contaminants from the ecosystem very difficult.

- The composition of the food chain is important in the movement of contaminants within the ecosystem (changes to the food chain affect contaminant movement).

- The maintenance of a healthy economy is essential to restoration of the Great Lakes, and in the future, economics must be assessed along with ecosystem stressors.

There are no *major* changes regarding these conclusions. This is not surprising, since it often takes many years of observation to note changes or to reach conclusions regarding an ecosystem's response to changes in stress, especially a system as large as the Great Lakes. An update on the states of ecosystem stressors and ecosystem health first evaluated in the background papers for SOLEC 94 follows.

1.2.1 Update on Aquatic Community Health Since 1994

1.2.1.1 Exotic Species

Zebra mussels. Range extensions of zebra and quagga mussels are continuing. In Lake Erie, their distribution has now extended to include soft sediments and vegetation. Colonization of deep-water sediments by quagga mussels appears to be having a negative impact on the native freshwater invertebrate *Diporeia*, which is a major component of the foodchain.

Ruffe. Ruffe (fish) have now extended their range from Lake Superior to Lake Huron and pose a threat to native species, especially perch.

Goby. Round goby (fish) are expanding their range throughout the Great Lakes, except in Lake Ontario. The species has been found in eastern Lake Erie and has become more abundant in central basin tributaries on the south shore of Lake Erie. Part of the goby's diet consists of zebra mussels, but its impact on native species is unknown.

Sea lamprey. Sea lamprey in northern Lake Huron are increasing in abundance. Inability to control sea lamprey in the St. Marys River seems to be a major factor in this population increase.

1.2.1.2 Community Structure

Lake Superior. The lake trout population in Lake Superior has recovered to the extent that stocking has been suspended.

Lake Michigan. Yellow perch continue to have problems and are in decline.

Lake Huron. The presence of ruffe has been confirmed in northern sections, at Alpena, Michigan.

Lake Erie. Lake Erie remains a very stressed ecosystem. Since 1990, walleye, smelt, and yellow perch populations have been declining largely as a result of decreasing productivity caused by zebra mussels and phosphorus control. Recent information has shown a possible recovery in yellow perch and walleye. Zebra mussel densities continue to increase lakewide. The unexpected finding of zebra mussels in soft sediments and vegetation means that zebra mussels are likely to continue increasing. The effects of zebra mussels in the Detroit River, Lake St. Clair, and Lake Erie have resulted in greatly improved water clarity in some nearshore areas. Associated with these elevated levels of zebra mussels in Lake Erie is the presence of summer blooms of blue-green algae, which are causing problems for water supplies. Finally, recent increases in round goby and the arrival of ruffe in Lake Huron, and their impending arrival into Lake Erie in the near future, create potential for more disruption of aquatic community structure.

Lake Ontario. The Lake Ontario ecosystem is experiencing a dramatic decline in productivity compared with its status in the seventies and eighties when levels of phosphorus were significantly higher as a result of human sources. Quantities of alewife (the principal prey for salmon and trout) continue to be lower than in the previous two decades. Decreasing nutrient loading from Lake Erie (due to reductions in phosphorus loading and the effects of zebra mussels) has contributed to the decline of alewife. On a positive note, lake trout are now showing increasing natural reproduction in Lake Ontario for the first time in 50 years. A recent sighting of a deepwater sculpin (*Myoxocephalus quadricornis*) indicates that this formerly "extirpated" native species may be recovering.

1.2.1.3 Overall Rating

While the overall evaluation of aquatic community health as *mixed/improving* has not changed, some notable changes have occurred in the status of both exotic species and community structure as stated above.

1.2.2 Update on Aquatic Habitat and Wetlands

The authors of the SOLEC 94 paper "Aquatic Habitat and Wetlands in the Great Lakes" believe that there has been little, if any, recovery in the status of these two features in the Great Lakes, with the exception of improvements in some Areas of Concern (AOCs). On the positive side, habitat has gained wider support as an issue needing attention, and is becoming important to more agencies and organizations.

The types of inventories and assessments proposed in the 1994 paper have not been undertaken. As a result, current and adequate trend information to measure gains or losses is not available. The authors do not know whether the limited restoration effects in AOCs and elsewhere are beginning to balance continuing losses. It appears that losses continue to substantially exceed gains.

1.2.2.1 Overall Rating

The overall rating for aquatic habitat and wetlands remains *poor*.

1.2.3 Update on Human Health

1.2.3.1 Trends in Environmental Levels of Contaminants

Contaminants. There is no evidence, over the past five years, of dramatic shifts in levels or types of bioaccumulating contaminants in tissues of residents of the Great Lakes basin. However, the levels of such contaminants in the tissues of people eating large amounts of Great Lakes fish continue to be several fold higher than in people who do not eat such fish.

Beach closings. Available statistics indicate persistent bacterial contamination on many beaches in the Great Lakes basin, especially in late summer. There are not enough studies of illnesses related to recreational use of Great Lakes waters to draw any conclusions regarding recent trends.

Drinking water. Outbreaks of cryptosporidiosis in several municipalities in the Great Lakes basin due to contaminated drinking water indicate that infectious diseases can still pose serious problems. However, treated drinking water from the Great

Lakes continues to provide an excellent source of drinking water.

1.2.3.2 Fish Consumption Advisories

Advisories to restrict consumption of fish because of bioaccumulating contaminants are in effect in many parts of the Great Lakes basin. However, according to the *Guide to Eating Ontario Sport Fish*, released on March 7, 1997 by the Ministry of Environment and Energy, Ontario fish are becoming safer to eat. The guide notes that most chlorinated contaminants found in fish are continuing to decline as a result of the bans and restrictions on chemical substances such as DDT, PCBs, mirex, toxaphene, chlordane, and dieldrin. In the Great Lakes, sampling showed that PCB (polychlorinated biphenyl) levels in Lake Huron salmon and trout are generally declining. In Lake Ontario, PCB levels in salmon and trout are slowly declining, resulting in some less restrictive advisories. For Lake Superior, however, toxaphene is still a major contaminant causing consumption restrictions, especially of lake trout. Contaminant levels remain low in most Lake Erie fish.

1.2.3.3 Contaminant Burdens in Humans

Studies of blood and breast milk samples show that levels of bioaccumulating contaminants in tissues of residents of the Great Lakes basin are similar to those in other regions in the temperate zone, and are lower than those in the far North and Arctic. No significant changes have been reported since 1994. Results of the Great Lakes human health effects research programs of the Agency for Toxic Substances and Disease Registry (ATSDR) and of Health Canada have shown an association between the consumption of contaminated Great Lakes fish and body burdens of persistent toxic substances (PTSs) such as PCBs, dioxins, chlorinated pesticides, and mercury. Here are some other findings of the programs:

- Susceptible populations included Native Americans/First Nations, sport anglers, elderly people, pregnant women, fetuses and nursing infants of mothers who consumed contaminated Great Lakes fish.

- A significant trend of increasing body burden was associated with increased fish consumption.

- Anglers consumed two to three times more fish than did the general population.

- Levels of contaminants in some Great Lakes fish were above the advisory limits set by the state and federal governments.

- Individuals who consumed Great Lakes sport fish for more than 15 years had contaminant levels in blood that were two to four times higher than non-fish eaters.

- In general, men consumed more fish than women did, and women consumed Great Lakes fish during most of their reproductive years.

1.2.3.4 Overall Rating

As in 1994, on the basis of the available limited information, the state of human health in the Great Lakes basin, as reflected by human exposure to persistent toxic substances, has been rated as *mixed/improving*.

1.2.4 Update on Toxic Contaminants

The most recent analysis of temporal trends in contaminant data in fish communities indicates that the long-term decline in contaminant levels continues, although at slower rates than in the past. However, as reported in the results of the 1996 “Workshop on Toxaphene in the Great Lakes: Concentrations, Trends and Pathways,” sponsored by U.S. Environmental Protection Agency, toxaphene concentrations in Lake Superior lake trout are the highest in the Great Lakes and have not decreased significantly. An overall slower decrease of those concentrations in Lake Superior is to be expected because of lake processes such as low sedimentation rates and long water-retention time, but the lack of decrease remains a puzzle that calls for further work.

1.2.4.1 Overall Rating

The overall rating for toxic contaminants in the Great Lakes remains *mixed/improving*.

1.2.5 Update on Nutrients

The authors of the paper on nutrients have reviewed the data since 1994 and have concluded that no appreciable change has occurred in the nutrient status of the Lakes and that the rating remains *good* in terms of achieving the targets for phosphorus reduction in the GLWQA.

1.2.6 Update on Economy

The Great Lakes basin economy continues to grow and adapt to the continental and global marketplace. The largest bilateral trade relationship in the world is concentrated in the basin and it also is expanding. This hub of economic activity is characterized and supported by strong resource, product and policy linkages. Recent employment trends have varied between the two sides of the basin; Canadian unemploment has remained relatively high, whereas U.S. job growth has been strong. Industrial restructuring, which has been underway since the 1980s, continues to mold the basin's prominent manufacturing sector through modernization of equipment and facilities making it more productive but with fewer workers. The long-term shift to the "service and information economy" will continue as business and personal services develop new markets and gravitate to growing metropolitan areas.

Urban sprawl in the Great Lakes basin and its associated environmental and socio-economic poblems continues. In some metropolitan areas within the U.S. portion of the basin, sprawling urban land uses consumed land at about ten times the rate of population growth during the past two decades. Even in cases where population growth has not occurred, additional land is still being rapidly consumed for urban uses. While the most visible form of sprawl continues at the outer edges of metropolitan areas, rapid land development is occurring in communities of all sizes including recreational development far from urban centers, especially along the lakeshores. The irreversible loss of farmland and natural habitat as a consequence of sprawl will continue until more efficient land-use practices are implemented. Urban revitalization efforts underway or planned including the cleanup and redevelopment of former factories, neighborhood improvements and targeted support for business expansion can make a difference for these central city places.

Pollution prevention has been enthusiastically accepted by many as the preferred approach to environmental management. However, the success of voluntary pollution-prevention programs is built upon on the foundation of a sound regulatory framework. Without a strong regulatory structure there is less incentive to implement new pollution-prevention activities. Those who provide pollution-prevention technical assistance often find businesses open to voluntary solutions to achieve environmental objectives required by regulations. Businesses are also increasingly receptive to the message that pollution prevention will improve their bottom line. Acceptance and advancement of pollution prevention continues.

1.2.6.1 Overall Rating

No change has occurred in the ratings of the ten indicators used in 1994: four indicators were rated as *mixed/improving*, four as *mixed/ deteriorating*, and two as *poor*.

2. Ecosystem Integrity and Biodiversity: Saving the Pieces

The state of the Lakes can be expressed in many ways, but a fundamental beginning point is the health of the ecosystem in terms of its integrity. The stated purpose of the U.S./ Canada GLWQA is to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem.

2.1 Integrity

"Integrity" is not specifically defined in the Agreement, but is understood to include the health of the biological populations and interactive communities of the ecosystem and their ability to withstand stress or adapt to it. Ecosystem integrity includes the good health of living things, the ability of systems to self-organize, and a physical and chemical environment that supports good health.

An important part of ecosystem integrity is genetic diversity. Ecological communities are dynamic and exist within ranges of conditions that occur as a result of natural forces. Communities exist in balance with these natural conditions, and their composition changes throughout various states that tend toward stability and increasingly complex interrelationships. Mature communities are relatively stable, compared to younger communities, and contain proportionately more organisms that take a long time to complete their life cycles. These communities also have more specialized and demanding habitat requirements.

The Great Lakes ecosystem, although subject to natural disturbances, was relatively mature and stable before the arrival of European settlers. Some stable communities of organisms have become rare because they are sensitive to human exploitation of the fisheries and landscape (for example, those uniquely associated with old growth forests or undisturbed wetlands). Part of the challenge of protecting the ecosystem is to maintain the full spectrum of all remaining species and ecological communities.

Another important aspect of ecosystem integrity is resiliency, or the ability of healthy systems to self-organize and recover from stress or disruption. In individual organisms this is known as "homeostasis": the tendency to maintain, or the maintenance of, normal, internal stability by coordinated responses of the organ systems that automatically compensate for environmental changes. A similar process takes place in ecosystems as a result of interactions between component parts.

2.2 Biodiversity

Resiliency is also an important aspect of biodiversity. It is the diversity of genetic traits within and among species that enables ecosystems to survive and prosper, even though challenged by changing conditions. The native species and living communities contain within their genetic makeup the “memory” of conditions over thousands of years, in which they have survived in the Great Lakes basin.

Ecosystems are dynamic in time scales measured from minutes to millennia, and continue to change and evolve. However, the speed of changes caused by unchecked human activity far exceeds the changes that occur naturally and does not give the system time to recover or organisms time to adapt or evolve.

As a result, ecosystem integrity can not be attained by simply “letting nature take its course”. What is needed, in addition to managing future human impact, is to save the remaining pieces of the system to ensure that they are not lost, and to provide conditions that allow recovery of the ecosystem. This would include prudent human intervention to facilitate recolonization by native organisms and reestablishment of healthy communities of native organisms. In this way ecosystem integrity can be restored and maintained.

Much of the Great Lakes basin ecosystem has been permanently altered, but viable remnants of most of the biological components remain. It is the native plants and other living communities that provide the best means of attaining ecosystem integrity and sustainability. Although any miscellaneous degraded assemblage of organisms would probably begin to evolve into new stable communities over tens or hundreds of thousands of years, we do not have that amount of time available.

It has been suggested that altered and reorganized ecosystems may be just as healthy as the original systems and that ecosystem outcomes can be selected by managers or public opinion. However, because the system is so complex, it is not possible to predict outcomes and because new species assemblages have not had time to evolve into functioning communities, they tend not to make full use of all available habitats, not to be able to tolerate the full range of natural conditions which occur over time, and to be unstable. Given these circumstances, the prudent choice appears to be management toward a goal of protecting and restoring the full range of ecosystems that existed at the time of European settlement.

Protection of high-quality areas that contain viable populations of species and/or communities that are rare or sensitive to human disturbance plays an important role in restoring and maintaining integrity and sustainability. This function includes protecting habitat necessary for all life stages of all species. Sufficient habitat and biodiversity must be protected to ensure survival in the event of catastrophic change in any one area.

Protection of viable populations and communities that represent the full range of nearshore ecosystems throughout the basin is essential. This cannot be accomplished by preserving a few ecological zoos containing representative samples. Protection must be given to fully functioning ecosystems throughout the basin. Living communities are complexes of thousands of interacting species including organisms such as bacteria, fungi, and nematodes.

Another aspect of maintaining integrity is preserving critical habitat. While exact definition or identification of critical habitat remains elusive, it is believed that some habitat is essential for survival of various species and genetic stocks or strains within species. Critical habitat is often associated with reproduction and protection of early life stages, but it can apply to all life stages, including migration.

2.3 Sustainability

Sustainable development is an important concept related to ecosystem integrity. Sustainable development seeks to meet the present needs of society without compromising the ability of future generations to meet their own needs. As a society, we are still falling far short of this goal since we continue to deplete our non-renewable resources and spend our ecological capital" by destroying unique habitats and biodiversity.

Every human society must solve and continue to solve the basic economic problems of producing the goods people need or want and distributing them where and when they are desired. For development to be ecologically sustainable, the knowledge gained from accumulated ecological insights into the impacts of human activities on the health and functioning of ecosystems must be fed back into the development process and be used to adjust those activities to protect the health and functioning of ecosystems.

Sustainable development is a direction toward an economy developed by technologies, land-use practices, laws, and institutions that take account of ecological understanding. The great challenge is to create ways of life and communities within which we humans prosper while our actions restore the natural life support system upon which all life and prosperity depends.

SOLEC 96 focused on two ecosystem integrity aspects of sustainability: (1) human use and economic development of the ecosystem should be sustainable in the long term; and (2) biological communities should be self-sustaining with minimal (or zero) human assistance.

Ecosystem integrity is measured both in terms of biological integrity and in terms of human health. Human health aspects of ecosystem integrity are difficult to assess because of the multiplicity of factors affecting human health. As reported in SOLEC 94, some direct evidence exists of human health effects resulting from exposure to pathogens and to persistent bioaccumulative toxic contaminants, but most information about human health relates to exposure to health risks.

3. State of Information

In order to report on the state of the Great Lakes ecosystem, we need to look at the state of available information itself. For SOLEC 96, the authors of a background paper examined two aspects: the availability of information on the condition of the Lakes; and the state of the databases themselves in terms of what exists and who is maintaining them. A full presentation is contained in the background paper Information and Information Management."

Timely access to reliable data is critical for not only determining the past and current state of nearshore ecosystems, but also defining and achieving future ecosystem management goals. Data have been collected and analyzed in the Great Lakes for many years by a variety of organizations, for a variety of purposes. A large amount of information has been gathered in response to the Great Lakes Water Quality Agreement over a period of decades and represents an excellent database for the deep-water areas. Much of that information, however, is limited to the water quality of offshore areas and contaminants in fish that spend most of their lives in offshore areas.

Information on nearshore areas is far less consistent since it has been gathered with a local focus, and nearshore areas vary considerably from place to place. The overall conclusion from the SOLEC 96 background papers and conference discussions is that there are no widely accepted indicators for measuring the state of the nearshore. Data have generally been collected for limited purposes on an as-needed basis by individual agencies, and their value in system-wide assessments is questionable. The conference sponsors have accepted this finding; identifying indicators for the nearshore areas will be a major theme for the 1998 conference.

One significant challenge is associated with the use of Great Lakes ecosystem health indicators: the sheer size of the basin and associated resources required to support long-term data collection efforts make it difficult to keep ecosystem health information up to date. In fact, there are only a few data sets that cover the entire Great Lakes shoreline.

Binational activities carried out under the Great Lakes Water Quality Agreement (Lakewide Management Plans, Great Lakes International Surveillance Plan) have provided major data coverage. Unless the data collection efforts are repeated however, the data quickly become out of date. On-going monitoring programs provide the best long-term data that can be compared over the years. However, a number of these programs seem to have been ended in recent years.

Four indicators were used to assess the overall state of data for all the indicators used in this report and the background papers: data coverage (how well the data cover the Great Lakes nearshore area); data time frame (how recent the data are); data applicability (how well data can be used to address the indicators discussed in this paper); and data usability (how well the data can be used across disciplines).

An evaluation of the overall state of data based on these four categories is presented in Table 1.

Even if standard ecosystem indicators were selected and data gaps remedied, a daunting task remains: information management. Information management involves the storage, manipulation, and transfer of information and data. A number of factors make the management of Great Lakes basin ecosystem information a challenging task. Something as basic as generating a list of the available data sets is very difficult because of a lack of adequate metadata (information that includes the identification of the researcher who collected the data, the date when data were collected, the level of accuracy maintained, and the collection method which). Another difficult issue is the availability of data for those who want to use it. Not only can formatting constraints pose

Table 1. Overall State of Data

Desired Outcome	Indicator	Rating	Basis for Rating
Data to measure all indicators	Data coverage	Fair	Only a few data sets cover the entire Great Lakes shoreline. Most are lake or site specific. Data collected on behalf of international studies (e.g. surveillance or Lakewide Management Plan studies) generally have the best data coverage.
	Data time frame	Fair	Some long term monitoring programs have excellent up to date data such as the water level information. Large data sets collected on a one time basis (e.g. shoreline classification) are becoming out of date.
	Data applicability	Fair	Most data sets have some applicability to the indicators described in this report. If they cannot be used directly, they can be used in support of measuring the indicator.
	Data usability	Fair	Some data are useable for a wide range of applications, while others are very study specific.

Source: Leger, W. and R. Greenwood. 1997. Information and Information Managment. (SOLEC Background Paper) problems, but questions related to ownership rights and revenue generation must also be answered.

The first step in meeting the challenges posed by information management involves developing standard methods for collecting, storing, and maintaining Great Lakes data. The data must also be made consistent across a range of computer systems in use throughout the region. One way to do this is to establish a database on the World Wide Web that contains references for all available Great Lakes data. As long as adequate metadata are available, decision makers and scientists from all over the basin would be able to access the database from their own offices and learn where information exists about a given nearshore topic. This type of system would eliminate the need to have actual data located on a Web site. Today's electronic technology should facilitate identification and access of data sources and assembly of information.

4. Indicators

How do we know whether the ecosystem we are striving to protect (or restore) is healthy or in need of help? Indicators can provide simple brief expressions of the state of the ecosystem based upon aspects that can be measured and accepted as characterizing its condition. Such indicators can cover various levels of the health of the ecosystem, including biological health, stressors, sources, and programs to deal with problems at all levels. In this report we focus on indicators of various aspects of nearshore ecosystem health.

The health of the living components of the ecosystem, including humans, is the ultimate indicator that reflects the total effect of stresses on the ecosystem. The effects of these stresses are often expressed as impairments and are the most meaningful indicators as far as most people are concerned. Is the system healthy and can we swim, fish, eat the fish, and drink the water? Although effects on the living system are the ultimate indicators, measures of the physical, chemical, and biological stressors and sources that affect the system are equally important in describing the state of the Lakes and in providing vital information for programs that address stressors and sources.

For the nearshore areas of the Great Lakes, there are no widely accepted or generally available indicators that can be used to summarize the state of the ecosystem. Consequently, the authors of the background papers and the SOLEC 96 conference organizers developed these indicators. All are based to some extent upon data, but the evaluation and rating assigned primarily amount to the best professional judgment by knowledgeable people.

For purposes of simplification, a small number of indicators for each of the background papers have been chosen for this report. These simple indicators are intended to summarize, in understandable language, the state of the ecosystem and progress being made in dealing with the many stressors and their sources. These indicators are presented in Tables 1, 4, 5, 6, 7, 8, and 9. The reader should note that there is some variation in the style of presenting the indicators. For example, Information and Information Management uses a rating of *good*, *fair* or *poor*. Nearshore Waters, Coastal Wetlands and Impacts of Changing Land Use use a rating system of *good*, *mixed* or *poor* in conjunction with a trend. Land by the Lakes: Nearshore Terrestrial Ecosystems uses a combination of letter grades *A to F*, trends and ratings of *good*, *mixed* or *poor*. More detail about each indicator can be found in each of the background papers.

In general, the ratings have the following meanings:

- *Poor*—significant negative impact.
- *Mixed*—the impact is less severe.
- *Good*—the impact or stress is removed and that the state of the ecosystem

Definition of the Term
"NEARSHORE AREAS"

For the purposes of SOLEC 96 and this report, the nearshore areas of the Great Lakes are defined in terms of living ecosystems, both on land and in the water.

The land areas are those ecosystems directly affected by the Lakes. The water areas are the relatively warm shallow areas near the shores. The nearshore zone also includes coastal wetlands that are dependent on lake levels. In both directions, nearshore areas are generally within 16 kilometers (10 miles) of shore. Exceptions are in Lake Superior, where warm water seldom extends far from shore, and in Lake Erie, where both the central and western basins are relatively shallow and warm and thus are considered to be nearshore" in their entirety.

On land, the nearshore zone is that area affected by the Lakes—waves, wind, ice, currents, temperature, and the rising and falling of lake levels that constantly shape and modify the entire shoreline.

In water, the nearshore zone consists of areas with enough warm water to support a community of warmwater fish and associated organisms. These areas represent approximately 25 percent of each of Lakes Michigan, Huron, and Ontario; 90 percent of Lake Erie; and only 5 percent of Lake Superior because of its very deep and cold nature. In general these are coastal areas of less than 30 meters (98 feet) in depth except in Lake Superior where they are less than 10 meters (33 feet) in depth. The nearshore waters also include the connecting channels and virtually all the major embayments of the system.

Beyond the nearshore areas and their lake-associated ecosystems (on land and in water), the SOLEC 96 background paper Impacts of Changing Land Use" discusses sources of stressors affecting the nearshore areas. These source areas extend upstream far beyond the nearshore area to include virtually the entire Great Lakes basin.

component is restored to a presently acceptable level.

In general, the trends have the following meanings:

- *Deteriorating*—the trend is towards greater impact.
- *Stable*—no change in the impact.
- *Improving*—the trend is towards less impact.

It is the intention of the Parties to the GLWQA, in SOLEC 98, to focus on the development of a set of indicators for the governments to report on the restoration and preservation of the Great Lakes basin ecosystem.

5. The Nearshore

The Great Lakes are bordered by 16,000 kilometers (10,000 miles) of shoreline, every kilometer of which represents a unique and dynamic intersection between life on land and life in the water. The Great Lakes nearshore ecosystem is defined by this intersection, and the ecological result is an array of unique habitats for the many species of plants and animals around the basin.

The Great Lakes basin ecosystem includes the Lakes and the entire area draining into them. The nearshore consists of interactive areas where the Lakes influence land and where land directly influences the Lakes. The remainder of the basin is important as a source of stressors affecting the nearshore.

The nearshore areas, both aquatic and terrestrial, are the most diverse and productive parts of the Great Lakes ecosystem and at the same time support the most intense human activity. As a result, the areas that contain the greatest biological resources are subject to the greatest stress. These are the areas most used by humans and where the majority of humans live (33 million residents live near the Lakes). Consequently, these are the areas with the most to save and the most to lose. Today, activities ranging from farming to city building and even recreation affect the basin's ecosystem.

Great Lakes nearshore areas suffer from a disproportionate environmental burden because of their distinctive and sensitive environments and proximity to development.

This report focuses on the unique physical environments found in the nearshore (especially the nearshore waters, the coastal wetlands, and the terrestrial nearshore—the land by the Lakes), the health of communities whose survival depends on those environments, the major stressors acting on the nearshore ecosystem, and the sources of those stressors.

5.1 The Nearshore Waters

5.1.1 Physically Unique

The nearshore waters occupy a band of varying width around the perimeter of each Lake, where the water is relatively warmer and shallower than the rest of the waters in the Lakes (Figure 4). For the SOLEC 96 conference and this report, the nearshore

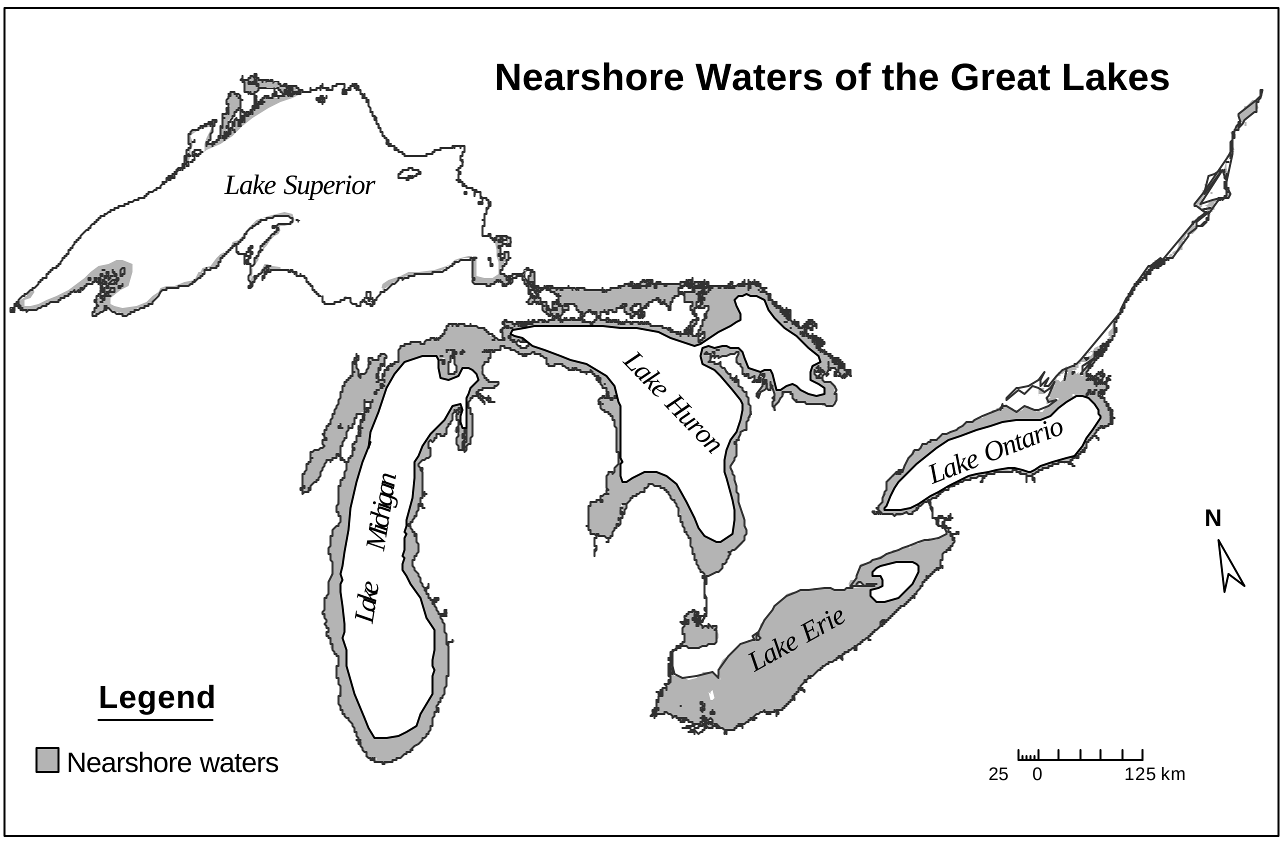

Figure 4. Nearshore Waters of the Great Lakes

Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

waters are defined in terms of depth and temperature. The amount of nearshore water in each Lake varies with the size and shape of that Lake's basin (see the nearshore definition above). If the Lake bed is very steep, the boundary between nearshore and offshore waters occurs relatively close to shore (less than 5 percent of Lake Superior is considered nearshore). If the Lake bed slopes very gradually, however, the boundary extends much farther out from the Lake edge (more than 90 percent of Lake Erie is considered nearshore).

The difference between nearshore and offshore waters is dictated by the temperature during the warmer, ice-free months of the year. Waters at different temperatures have different densities and, as a result, warmer, less dense waters near a lake surface do not mix with cooler, denser waters deeper in a lake. When the exchange between nearshore and offshore water is limited, both plant and animal communities are affected. Nutrients that enter a lake via land runoff or point source discharges are mostly available in the nearshore; suspended sediments that are delivered by river outflows have their primary effect in the nearshore; and pollution that is discharged into the nearshore waters is concentrated there. These effects are particularly noticeable during the spring season before warmer water spreads over the surface of a lake.

The Great Lakes connecting channels (the large rivers carrying the surface-water outflow from one Great Lake to the next) and the

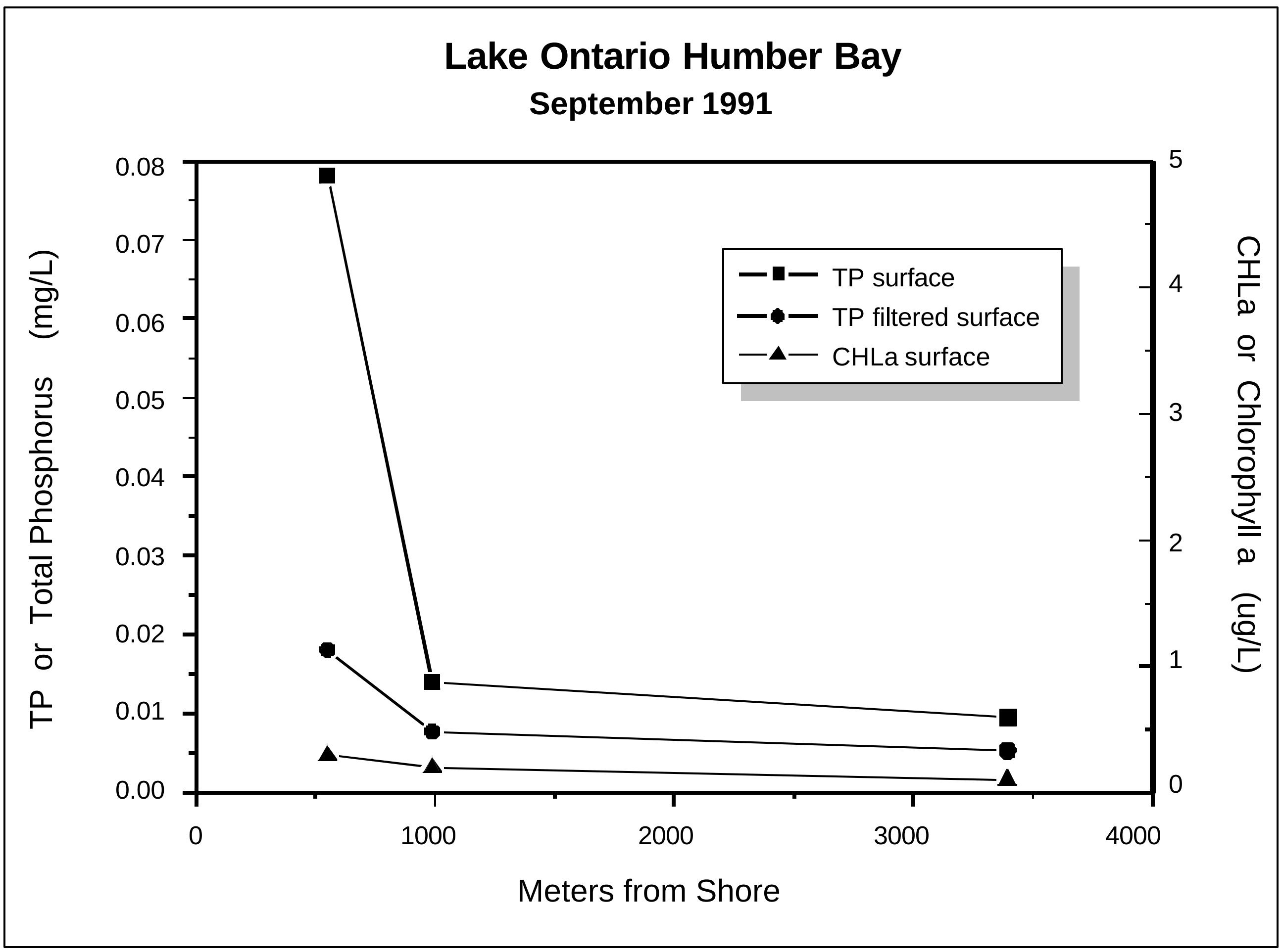

Figure 5. Phosphorus and Chlorophyll *a* Gradients in Lake Ontario
Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

lowest reaches of all Great Lakes tributaries are also considered nearshore waters. Water discharged through tributaries into the nearshore waters contains materials and energy from the terrestrial and aquatic inland components. Thus, the nearshore waters are physically and biologically linked with other ecosystem elements in the basin.

Nutrient levels can be significantly higher in the nearshore since nutrients are introduced to a lake at the shore both by sewage sources and by rivers. Sewage treatment plant effluent and combined storm outflows influence nearshore water quality near population centers. Though sewage plants remove much of the phosphorus from sewage, they do not eliminate it. Many treatment plants discharge effluents with phosphorus concentrations in the range of 1,000 micrograms per liter, which is 100 times the desired concentration in the open waters of, for example, Lake Ontario. Thus, nearshore-offshore gradients are to be expected. An example of this gradient can be seen in Figure 5.

5.1.2 Health of the Nearshore Waters

While the past 25 years have seen general improvements in nearshore aquatic ecosystem health, ample evidence still exists that physical, chemical, and biological stressors continue to have a negative impact on nearshore populations.

The state of the Great Lakes fish community is one important indicator of nearshore aquatic ecosystem health, since virtually all species of Great Lakes fish use the nearshore waters for one or more critical life stages or functions. The health of the fish community as an indicator has been assessed as part of the status of native species and their habitat, and is rated as *mixed/improving* in Table 4. For some species, the nearshore area is a permanent residence; for anadromous fish, the nearshore is a migratory pathway; and for other offshore species, the nearshore provides temporary feeding and nursery grounds. Shallow waters act as a refuge for young-of-the-year fish, complete with submergent vegetation for food and protection, and warmer temperatures that speed growth. Only deepwater ciscoes (members of the whitefish family) and sculpins are rarely found in the nearshore waters.

During the summer, the nearshore waters are occupied by aquatic plant and animal communities that are adapted to the summer thermal conditions there. Each species of fish has a narrow and relatively unique range of summer temperatures at which the fish grow best. Fish actively seek their preferred range during the summer, resulting in distribution of species based upon thermal conditions. An outcome of this is that not all areas of nearshore habitat are available to all species.

Historically, the loss of biodiversity and the establishment of non-indigenous species have been little short of catastrophic to the Great Lakes fish population. Most species were severely reduced in numbers, with many genetic strains and some entire species lost entirely. Although many fish communities remain unstable, management efforts are working to restore stability. Fish-stocking activities take place throughout the basin and habitat restoration projects are becoming more common. Signs of success include populations of lake trout reproducing again in Lakes Superior and Michigan, and beginning to reproduce in Lake Ontario; walleye and yellow perch once again being abundant in Lake Huron; and lake whitefish showing good recovery throughout the Lakes. The recovery of native fish stocks alone, however, has been insufficient to support the Great Lakes fisheries. Non-native species such as Pacific salmon, rainbow trout, and brown trout have been stocked successfully, and have contributed to the stability in Great Lakes fisheries, resulting in an industry worth more than U.S. $4 billion annually. Over 80 percent of this is retained in the Great Lakes basin, much of it having a significant impact on small lakeshore communities.

In spite of a heightened awareness of the importance of maintaining high-quality fish habitat, there are still many cases of habitat destruction that threaten the survival of Great Lakes fish populations—for example, shoreline modification. Natural shorelines are often armored to eliminate erosion that is caused by wind and wave activity. Artificial hardening of the shoreline can redirect wave energy, changing sand distribution and causing erosion downshore. Irregularities in the shoreline are often straightened, changing the longshore currents, which in turn decrease local variation in the lake bed. The ultimate result is a significant reduction in the amount of fish habitat.

Habitat is also disrupted by the passage of large commercial vessels through harbors and connecting channels. These ships cause rapid fluctuations of water levels and disrupt normal flow conditions to such a degree that submerged aquatic plants are fragmented or uprooted, and the substrates that provide attachment for these plants are eroded. Recreational watercraft can also cause similar problems with their wake and propeller action. The result is a substantial increase in the living plants, decaying plants, and benthic (bottom-dwelling) invertebrates that are destroyed, leaving valuable fish habitat degraded. A more detailed explanation can be found in section 8.7. The status of native species and their habitats is an indicator which has been rated as *mixed/improving* in Table 4.

A common forage fish, the spottail shiner, was used to monitor chemical contaminants in the nearshore in a 1993/94 study that sampled a total of 44 sites on Lakes Huron, St. Clair, Erie, and Ontario, and on the St. Clair, St. Lawrence, and Detroit Rivers. Higher contaminant values in the sampled fish were generally more frequent in the lower Great Lakes, with the maximum observed values noted at the Grasse River and Reynolds Aluminum sites in the St. Lawrence River and at the Welland Canal (Figure 6). In general, contaminant trends have been declining since the mid-1970s. The levels of contaminants in spottail shiners was assessed as part of the indicator for levels of persistent toxic substances in water, sediment, fish, and wildlife and was rated as *mixed/improving* in Table 4.

There is strong circumstantial evidence from laboratory exposure studies and field observations, linking the occurrence of cancerous tumors in fish with exposure to localized areas of sediments that are contaminated with chemical carcinogens, such as polynuclear aromatic hydrocarbons (PAHs). Tumors have been found in populations of bottom-dwelling species, including brown bullhead, white sucker, common carp, bowfin, and freshwater drum. Epidermal papillomas (tumors on the skin that appear as raised lumps or bumps, which may become cancerous) have been found on brown bullhead in a number of locations, with highest incidences at locations with elevated levels of PAHs in the sediment. Table 2 shows tumor frequencies in brown bullhead populations at selected sites (Figure 7). External tumor frequency exceeded 40 percent in Hamilton Harbour and 50 percent in Presque Isle Bay, and these tumors were prevalent in about 25 percent of the populations in the Buffalo and Black Rivers. Buffalo River and Presque Isle Bay also had about 20 percent incidence of liver tumors, and the Cuyahoga and Detroit Rivers had about 8 to 10 percent prevalence. All these sites have elevated levels of PAH in at least some portion of their sediment and have been designated Areas of Concern. Bullhead from two relatively uncontaminated sites had a liver tumor prevalence greater than 5 percent, though these populations had a greater percentage of older fish (age 5 and up) than the industrial sites. Tumor frequency tends to increase with age in brown bullhead populations.

Figure 6. Contaminant Concentrations in Spottail Shiners
Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

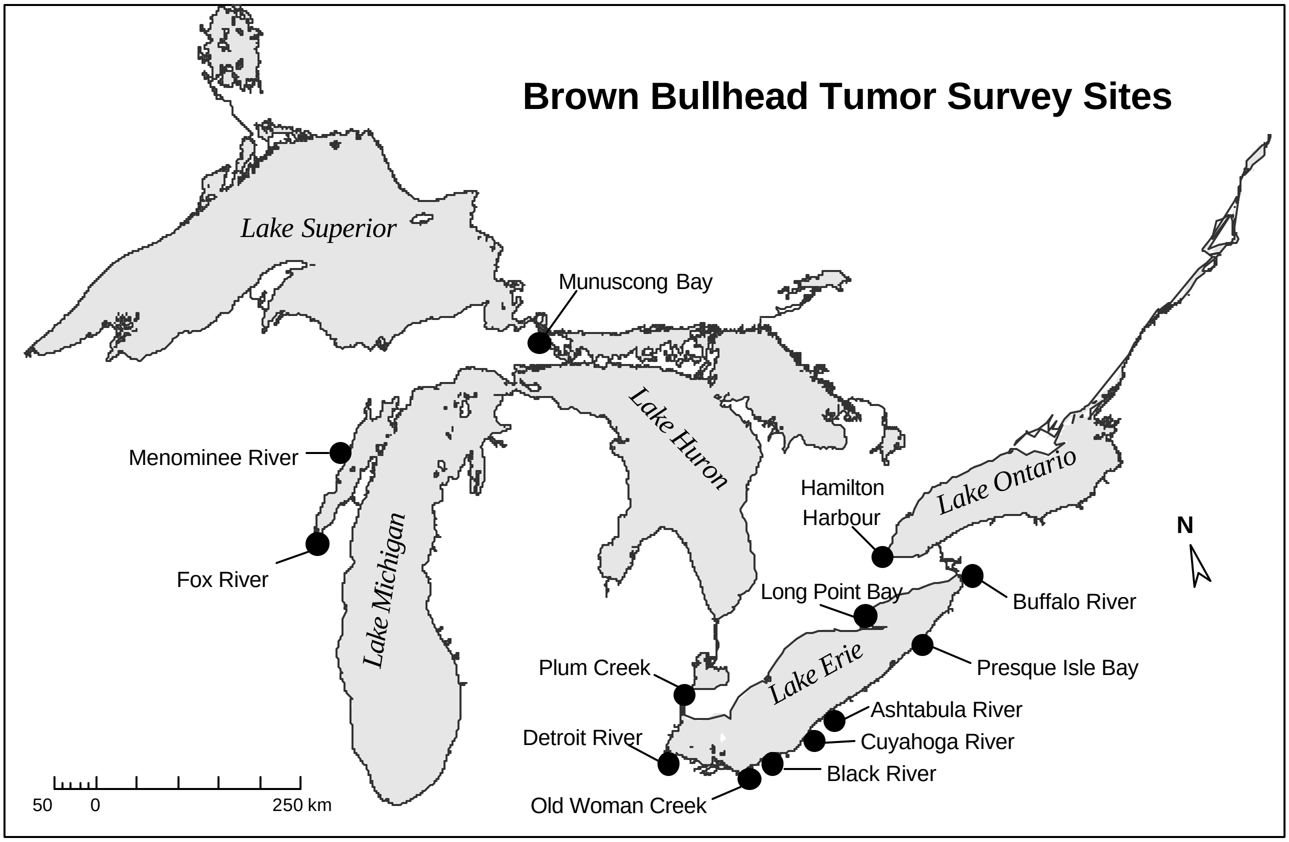

Figure 7. Brown Bullhead Tumor Survey Sites
Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

While dredging is one method of solving contaminated sediment problems, it may create more problems for the aquatic community, at least in the short term, as illustrated in the following example. In 1982 a population of bullhead located near an operational coking facility at a steel plant on Ohio's Black River had a liver cancer prevalence of 38.5 percent. The coking facility was closed in 1983, and by 1987, PAH concentrations in surficial river sediment had declined to 0.4 percent of the concentration that had been measured in 1980. By 1987, the cancer frequency in the bullhead population had also declined, to about one-fourth of that measured in 1982. Areas of sediment most contaminated with PAH were subsequently dredged from the river in 1990. Two years later the cancer incidence in bullhead exceeded that in 1982. This case illustrates that additional sedimentation can be effective in reducing the incidence of cancer in bullheads in some systems, whereas dredging with traditional methods can result in at least a temporary increase in cancer incidence and degradation of the health of native species because toxic contaminants are released from the sediments. This points to the importance of thorough analysis of positive and negative, long-term and short-term impacts of dredging in planning for remediation. The status of contaminated sediments has been assessed as one part of the indicator for levels of persistent toxic substances in water, sediment, fish, and wildlife and has been rated as *mixed/improving* in Table 4.

Biological stressors also play an important role in dictating the health of the nearshore aquatic ecosystem. While managers spend millions of

Table 2. Prevalence of Tumors in Brown Bullhead Populations in Waters of the Great Lakes Basin

Location	Collection Date	External Tumors		Liver Tumors	
		Neoplasms (%)	Malignancies (%)	Neoplasms (%)	Malignancies (%)
Ashtabula River, OH	1991	16.0	NA	6.2	3.1
Black River, OH	1982 1987 1992 1993	 25.0	 NA	60.0 32.5 58.0	38.5 10.0 48.0
Buffalo River, NY	1988	23.0	NA	19.0	5.0
Plum Creek, MI	1985	7.0	NA		
Cuyahoga River, OH	1984	8.9	5.5	9.4	NA
Menominee R., WI and MI	1984	2.1	NA		
Fox River, WI	1984	7.7	1.9		
Detroit River, MI	1985-87	10.0	NA	8.8	NA
Hamilton Harbour, ON*	1994	41.0	NA	4.5	0
Presque Isle Bay, PA	1992	56.0	33.0	22.0	6.9
Long Point Bay, ON**	1985	15.0	NA		
Munuscong Bay, MI**	1984	3.2	NA	5.9	2.9
Old Woman Ck., OH**	1984-85 1992-93	2.5	NA	 5.6	 3.2

Source for Table 2 (except Hamilton Harbour data): Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

* Source: Victor Cairns (1997) Personal communication. Department of Fisheries and Oceans Canada, Canada Centre for Inland Waters, Burlington, Ontario.

** Reference site in relatively pristine area.

NA means that brown bullheads from that site have not been analyzed for malignancies.

dollars on controlling the impact of non-native (or exotic) species, such as the sea lamprey, on fish populations, other exotic species continue to affect the nearshore system. For example, *Bythotrephes* is an exotic zooplankton species, which was introduced into the Great Lakes in the 1980s. Zooplankton are the primary (or first level) consumers in the aquatic food chain; they filter and eat algae, and their growth provides energy and nutrients in a form usable to fish. *Bythotrephes* have disrupted the native food chain because they eat other zooplankton (placing additional stress on the native zooplankton population) and compete directly against young-of-the-year fish.

The zebra mussel is a more commonly known invader, which has also had a dramatic influence over the state of the nearshore aquatic ecosystem. One significant negative impact of the zebra mussel has been the

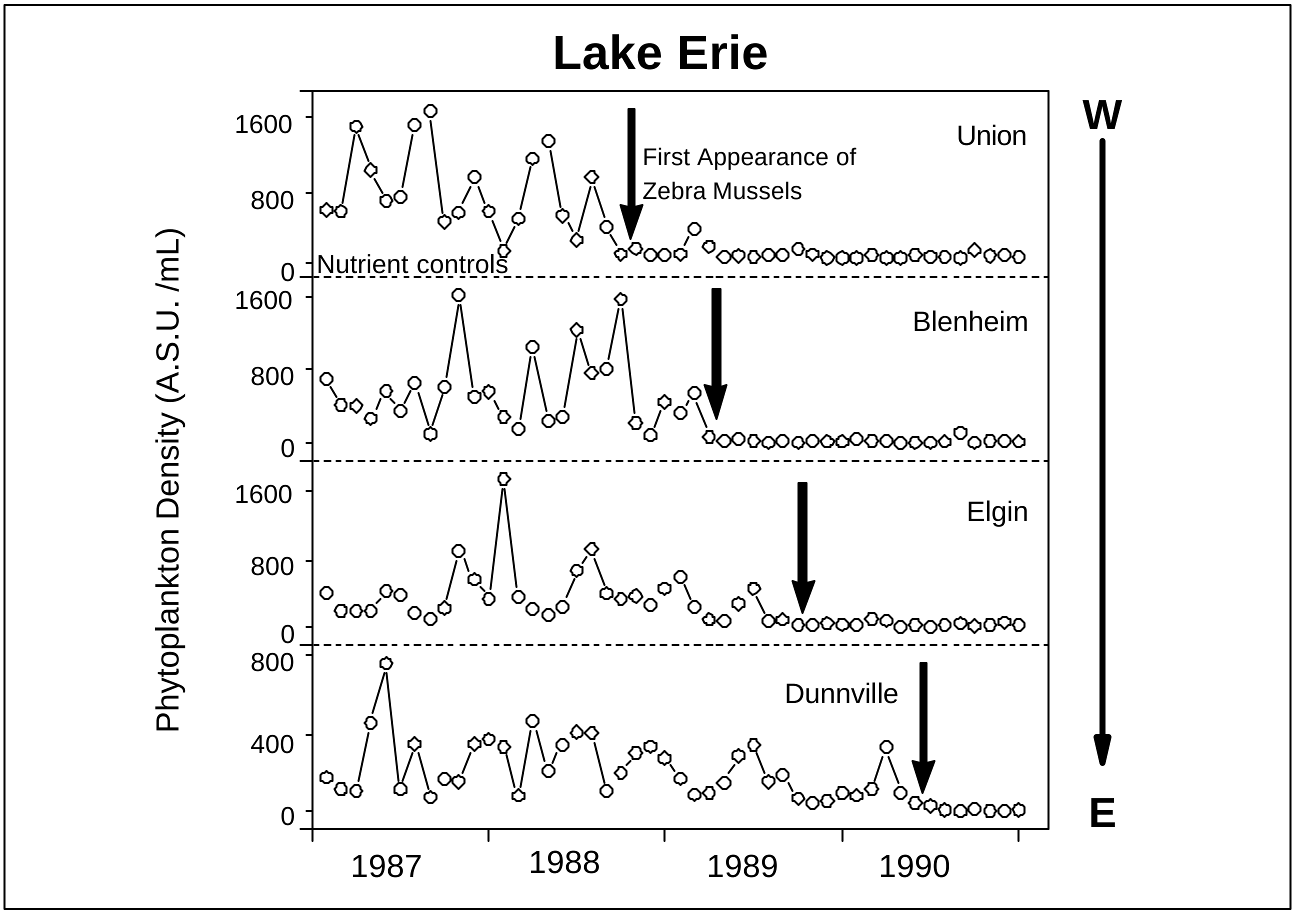

Figure 8. Phytoplankton Density in Lake Erie, Showing the Effect of Zebra Mussels
Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

substantial reduction in species and numbers of large freshwater clams. The Lake St. Clair-western Lake Erie corridor once had the richest and most diverse assemblages of large freshwater clams in North America. Within six years of the discovery of the zebra mussel in this region, freshwater clam populations in the region had declined to almost zero. Biodiversity has declined sharply as the functional community has shifted from a stable, slow-growing, multi-species clam community in balance within the ecosystem to a single-species population of zebra mussels with a relatively high turnover rate of energy that strongly affects ecosystem dynamics.

Zebra mussels have had other impacts on the nearshore aquatic ecosystem—one of which is shown in the following example. Zebra mussels feed by filtering particles from the water. This filtering process affects the nearshore ecosystem food chain because phytoplankton and smaller zooplankton, along with other suspended materials including pollutants, are removed from the water by the zebra mussels and biodeposited at the bottom of the lake. This process greatly *reduces* the plankton community (Figure 8) and, therefore, reduces the amount of food available to planktivorous (plankton-eating) fish that feed above the bottom. In turn, the process greatly *increases* the food supply for benthic communities and bottom-feeding fish. The result has been an increase in benthic species, and those considered to be pollution-sensitive have since become dominant. The impact of exotic species on the Great Lakes aquatic nearshore

Table 3. The State of Nearshore Bird Populations

Type	Species	Frequency	Population
Colonial waterbirds	Ring-billed	Common	Stable or Increasing
	Herring gulls	Common	
	Double-crested cormorants	Common	
	Caspian tern	Common	
	Great blue heron	Common	
	Great egret	Uncommon	
	Great black-backed gull	Uncommon	
	Common tern	Common	Stable/Variable
	Black-crowned night-heron	Common	Stable/Variable
	Black tern	Uncommon	Decreasing
	Forster's tern	Uncommon	
	Little gull	Uncommon	
Waterfowl	Dabblers	Common	Stable
	Geese	Common	Stable
	Bay ducks	Common	Stable/Variable
	Mergansers	Common	Stable
	Goldeneye	Common	Stable
	Seaducks	Common	Increasing
Piscivorous raptors	Osprey	Varies with location	Stable or Increasing
	Bald eagle	Varies with location	Stable

Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

has been evaluated as *poor/deteriorating* in Table 4.

A different factor influencing benthic communities is the improvement in oxygen levels in bottom waters of harbors and some open lake areas such as the central basin of Lake Erie where populations of the burrowing mayfly are showing dramatic recovery, providing evidence of improved benthic conditions. These changes result primarily from pollution control although that may be complemented by the activity of zebra mussels.

Another indicator of the state of the nearshore aquatic ecosystem is the health of the wildlife population. Table 3 illustrates the state of bird populations dependent on nearshore waters. While the populations of most colonial waterbird, waterfowl, and fish-eating raptor species are stable or increasing, notable exceptions are the black tern, Forster's tern, and the little gull. Interestingly, zebra mussels may have provided a winter boost for the duck species that feed on molluscs. However, the long-term impacts on waterfowl populations are not known.

5.1.3 Human Health

Sufficient evidence exists that consumption of contaminated sport fish and wildlife can significantly increase human exposure to Great Lakes pollutants because of bioaccumulation and biomagnification in the food chain. A series of studies in the 1980s linked PCB exposure in humans to consumption of contaminated fish. More recently, it has been demonstrated that consumers of contaminated Great Lakes fish can have body burdens of PCBs, mercury, and lead that are twofold to fourfold higher than those in the general population.

Just as fish consumption advisories indicate the level of toxic contaminants entering the water, beach closures and drinking water advisories act as indirect indicators of nearshore water quality. In Canada and the U.S., most public beaches are monitored to help ensure that bathers are protected from contact with polluted water. However, water sampling and microbiological testing procedures have not been standardized throughout the Great Lakes basin. Also, the kinds and levels of microbes and pollutants found on any given beach can vary with the type of contamination (for example, storm-sewer outfalls, agricultural chemicals and wastes, or industrial pollution), with water currents and water temperature, with nutrient levels, and with the number of beach users, etc. These variables make it difficult to see patterns or trends in the microbial quality of nearshore waters at public beaches across the Great Lakes, or even at any one given beach.

The nearshore waters may contain disease-causing organisms (for example, viruses, bacteria, and protozoa) that can cause gastrointestinal illness and ear infections as a result of swimming. Overall, beach closings are generally due to elevated levels of bacteria, but take place less frequently in northern regions, where human population is low and there has been little industrial development. Conversely, more closings occur in southern regions, where the shoreline is more intensely developed, population densities are high, extensive industrial and agricultural development has taken place and water temperatures along the nearshore are warmer.

During this century, waterborne infectious illnesses became rare in the Great Lakes basin, owing to effective treatment of drinking water and sewage by chlorination, and to immunization programs. Prior to the treatment of drinking water, waterborne illnesses such as typhoid fever and cholera could affect a significant proportion of an urban population. For example, in 1854, Chicago experienced a cholera epidemic in which 5 percent of the population perished, and in 1891, the death rate due to typhoid fever reached a high of 124 per 100,000 people. However, even modern water treatment plants have weaknesses. In 1993, about 400,000 inhabitants of Milwaukee became infected (about 4,000 were hospitalized) by a protozoan parasite (*Cryptosporidium*). A smaller outbreak of cryptosporidiosis occurred in Collingwood, Ontario, in 1996.

Some sewage treatment plant discharges are not disinfected before release, especially during storm flows, and thus contribute to the pathogenic load of nearshore waters. In addition, some sewage plant effluents, especially those carrying industrial wastes, are toxic to algae and probably also to other aquatic organisms. Other effluents such as agricultural runoff also contain pathogens and toxic chemicals. The chemical disinfectants used to kill pathogens in sewage and in

Table 4. Indicator Ratings for the Nearshore Aquatic Ecosystem and Stressors

Desired Outcome	Indicators	Condition	Trend
Healthy fish and wildlife	Effect of exotic species	Poor	Deteriorating
	Status of native species and their habitats	Mixed	Improving
Virtual elimination of persistent toxic substances	Levels of persistent toxic substances in water and sediment	Mixed	Improving
	Concentrations of persistent toxic substances in fish and wildlife	Mixed	Improving
Reduced nutrient loading, eliminating eutrophication	Dissolved oxygen concentrations of bottom waters	Good	Improving
	Water clarity/algal blooms	Mixed	Improving
Healthy human populations	Fish consumption advisories	Mixed	Improving
	Beach closings, measured in median number of consecutive days closed for a given year	Inadequate data	Unknown
	Drinking water quality	Good	Stable
	Acute human illness associated with locally high levels of contaminants	Inadequate data	Unknown
	Chronic human illness	Inadequate data	Unknown
Overall state of the Great Lakes aquatic nearshore ecosystem		**Mixed**	**Improving**

Source: SOLEC 96 Steering Committee

drinking water can also create toxic by-products.

Sewage water and drinking water are usually disinfected through the use of chlorine and occasionally ozone. Historically, municipalities began treating drinking water to prevent waterborne disease, by adding chlorine as a disinfectant. This proved to be a simple solution to a very serious public health problem. Chlorine is still used because it can kill pathogens throughout the water distribution system. Human health indicators have been evaluated in Table 4 and range from *good/stable* to *mixed/improving*. However, for many of the indicators there are inadequate data available to determine a rating.

5.1.4 Overall Rating

Table 4 summarizes the state of nearshore aquatic ecosystem health. The indicators that have not been discussed in this report are supported in the background paper "Nearshore Waters of the Great Lakes".

Figure 9. Different Types of Great Lakes Coastal Wetlands
Source: Maynard, L. and D. Wilcox. 1997. *Coastal Wetlands*. (SOLEC 96 Background Paper)

Figure 10. Shifting Plant Communities in Coastal Wetlands
Source: Maynard, L. and D. Wilcox. 1997. *Coastal Wetlands*. (SOLEC 96 Background Paper)

5.2 The Coastal Wetlands

5.2.1 Physically Unique

There are four basic types of wetlands: marshes, swamps, bogs, and fens. Marshes and swamps are the most common types of wetlands found in coastal areas because their vegetation can tolerate the large short- and long-term fluctuations in water levels of the Great Lakes. Although bogs and fens are more rare, they too are represented in sheltered areas adjacent to the Lakes.

Great Lakes coastal wetlands are shaped by dynamic lake processes, including waves, currents, and fluctuations in water levels, both long-term and seasonal. They are vibrant and unique areas of unrivaled importance to the life of the Lakes. They occur along the shorelines of the Lakes in areas where the erosive forces of ice and wave action are low, thus allowing the growth of wetland plants. Figure 9 illustrates the variety of wetland types.

The ecological characteristics of Great Lakes coastal wetlands are controlled by natural stress. Seasonal and long-term water-level fluctuations represent the most important source of stress, limiting the invasion of woody vegetation by causing lakeward or landward shifting of plant communities (Figure 10). Individual wetland species and vegetative communities prefer, and have adapted to, certain water depth ranges, allowing wetlands to be more extensive and more productive than they would be if water levels were stable. Differences between long-term recorded all-time high and low water levels range from 1.1 to 2 meters (3.6 to 6.5 feet) depending on the Lake.

5.2.2 Health of Coastal Wetlands

An assessment of the state of Great Lakes coastal wetlands must begin with the recognition that many of the original coastal wetlands no longer exist. Humans have drained, filled, and dredged coastal wetland areas for decades. The majority of these activities took place on the Lower Lakes, for agricultural, urban, and industrial land uses. For example, in western Lake Ontario from the Niagara River to Oshawa, 83 percent of the original 3,900 hectares (9,637 acres) of marshland were mostly lost to urbanization. Even larger losses occurred on Lake Erie over the last century and a half, especially in the western basin. Prior to 1850, there were 122,000 hectares (301,465 acres) of coastal marsh and swamp between Vermillion, Ohio, and the Detroit River, Michigan (part of the Black Swamp, a vast wetland complex). These wetlands were largely cleared, drained, filled, and diked to provide agricultural land in the late 1800s. Losses continued so that by 1987 only 5,300 hectares (13,090 acres) of Ohio's coastal marshes remained.

While the area of wetlands lost each year is now far less than in previous years, this is largely because so little remains. Current losses are a serious problem, as is continuing loss of quality even in protected areas. Little data are available on the rate of loss in quality, but where ecological processes such as natural water-level variations are disturbed or when wetlands are invaded by exotic species, they lose their ability to support sensitive species as well as their complexity and resiliency.

More recently, an appreciation has been gained for the vital role that coastal wetlands play in the maintenance of Great Lakes ecosystem health. Coastal wetlands protect nearshore terrestrial ecosystems from erosion by storing flood waters and dissipating wave energy; they reduce turbidity and improve water clarity in adjacent aquatic systems through sediment control; and they use a combination of physical, biological, and biogeochemical processes to improve water quality. Coastal wetlands are also home to a variety of plant and animal species. Over 90 percent of the approximately 200 fish species in the Great Lakes directly depend on coastal wetlands for some part of their life cycle. In addition, a number of species of birds, amphibians, reptiles, and mammals also depend on wetland habitat. Wetlands in general are known to provide habitat for many of the plant and animal species listed as threatened or endangered. About one-quarter of the fish species, two-thirds of the birds, and three-quarters of the amphibians listed as federally threatened or endangered in the U.S. are associated with wetlands.

While a comprehensive review of the state of remaining wetlands requires further research, it is possible to indirectly assess the health of the Great Lakes coastal wetlands by reviewing the stressors acting on them.

The degree of water-level fluctuation in the Great Lakes is an indirect indicator of coastal ecosystem health. Coastal wetlands depend on seasonal and long-term water-level fluctuations. When water levels are regulated, the natural range, frequency, timing, and duration of water-level changes are affected. As a result, the extent and diversity of wetland plant communities are reduced, and habitat for wetland fauna is altered. One consequence of this subtle yet pervasive environmental alteration is that coastal wetlands become more susceptible to invasion by exotic species, such as purple loosestrife, or aggressive native plants, such as reed canary grass[1]. These two species have established themselves in coastal wetland ecosystems, forming dense clumps (often in large, single species stands) that can choke out more beneficial native plants and therefore reduce habitat diversity. Purple loosestrife is particularly destructive because it has little or no value as food or cover for wildlife.

A second indirect indicator of coastal wetland health is the type of land-use activity taking place in the watershed surrounding coastal wetlands. Agricultural, residential, and industrial developments affect coastal ecosystems in a number of ways. In addition to having a direct physical impact, they increase the volume of sediment entering coastal wetlands and as a result bury fish-spawning areas. The increased sediment also decreases water clarity and light penetration into the water, thereby limiting the growth of the aquatic plants that form the base of the food chain. Finally, the high turbidity that results also restrict feeding by desirable sight-feeding fishes and favor introduced species like common carp, which can feed by taste and smell in highly turbid waters. Other impacts associated with these types of land uses include nutrient enrichment and increases in toxic chemical concentrations.

The extent to which wetlands are diked is a third indirect indicator of Great Lakes coastal wetland health. Diked wetlands are believed to solve management problems under circumstances where protection from water-level change and wave action is required or to help manage waterfowl habitat. However, diking also creates problems for wetlands. Isolation from the lake waters and the surrounding landscape results in the elimination or reduction of many of the functional values of wetlands, including flood conveyance, flood storage, sediment control, and improvement of water quality. Habitat for waterfowl and certain other animals may be improved by diking, but shorebirds and many less common plants and animals lose the habitat provided by a continually changing boundary between land and water. In addition, fish and invertebrates not capable of overland travel have no access to diked marshes and lose valuable habitat. Fish larvae pumped into diked wetlands during filling operations cannot leave and are thus lost to the lake population.

5.2.3 Overall Rating

The overall state of coastal wetlands in the Great Lakes ecosystem is only partially known, and that is why an overall rating could not be given. No inventory or evaluation system is in place for the majority of coastal wetlands. The general locations of coastal wetlands are known from remote sensing and aerial photography, but there is no commonly accepted system of classification nor is there systematic information on their quality, rate of loss, or rate of degradation. Much is known about the stressors that degrade wetlands and the conditions of some areas have been relatively well studied, but it is not possible at this time to provide a comprehensive review of the state of Great Lakes coastal wetlands.

Table 5 summarizes the state of coastal wetland ecosystem health. A more detailed review can be found in the background paper "Coastal Wetlands of the Great Lakes."

[1]The origin of reed canary grass is uncertain—it may be indigenous to the Great Lakes region or other parts of North America—but it became prominent in some Great Lakes coastal wetlands as a result of human actions.

Table 5. The State of Coastal Wetlands Ecosystems and Stressors

Desired Outcome	Indicators	Condition	Trend
Preserve or restore wetland area	Land-use changes, encroachment, development	Poor	Deteriorating
	Land use adjacent to wetland	Poor	Deteriorating
	Wetland size, abundance: Upper Lakes Lower Lakes	Mixed Poor	Deteriorating Deteriorating
	Shoreline modification	Poor to mixed	Deteriorating
Preserve or restore wetland area	Water-level fluctuation: Lake Ontario Lake Superior Unregulated lakes	Poor Poor to mixed Good	Stable Stable Stable
	Protection from erosive forces	Inadequate data	Unknown
	Levels of nutrients and persistent toxic chemicals	Mixed	Improving
Preserve or restore health of the habitat	Status of plant communities	Mixed	Deteriorating
	Status of individual plant species	Mixed	Deteriorating
Preserve or restore healthy fish & wildlife populations	Effect of exotic species	Poor	Deteriorating
	Concentration of persistent toxic substances in biota	Mixed	Improving
Overall state of the Great Lakes coastal wetlands ecosystems		**Inadequate data**	**Unknown**

Source: SOLEC 96 Steering Committee

5.3 The Land by the Lakes

5.3.1 A Unique and Diverse Landscape

The land by the Lakes (nearshore terrestrial ecosystems) is defined by the Lakes themselves. It is the product of ancient glacial sculpting, continuous etching by waves and wind, longshore currents, and the steady deposit of sediment by more than 500 tributaries that constantly modify the 16,000 kilometers (10,000 miles) of shoreline. It may be as narrow as a beach weathered by wind or as wide as a forest or dune field that extends several kilometers inland. It includes unusual land features such as the towering rock cliffs of Lake Superior's north shore, the dune and swale topography of southern Lake Michigan, the rich-soiled prairie/savanna landscape of Lake Erie, and the thin-soiled alvars of northern Lake Huron and eastern Lake Ontario.

This ever-changing shoreline acts as a buffer zone between the aquatic ecosystem and inland terrestrial ecosystems, and interacts with coastal wetland systems. Sand dunes, bars, and spits, for example, shelter coastal marsh and lagoon habitats. Sand beaches are the staging ground for transferring sand inland to create dunes. Nutrients, algae, and coarse, woody debris that collect on nearshore beaches provide food for birds, fish, amphibians, mammals, and microscopic organisms. Nearshore ecosystems provide important habitat for aquatic invertebrates with short adult life cycles, and are spawning areas for amphibians. They are critical habitats for migratory birds.

The unique shoreline ecosystems support a diversity of plant and animal species. Nearshore terrestrial ecosystems are living, resting, or feeding places for rare or globally imperiled species such as the piping plover and the Karner blue butterfly. Several species, including the Michigan monkey flower and the Kirtland's warbler, are found only in the Great Lakes region. The character of the Great Lakes results from a combination of unique physical attributes and rich biological communities.

5.3.2 The Health of the Land by the Lakes

The health of the land by the Lakes, nearshore terrestrial ecosystems, is degrading throughout the Great Lakes. This conclusion was reached by viewing the nearshore terrestrial environment from three perspectives: the ecoregions within the Great Lakes basin, the special ecological communities along the lakeshore, and the status of individual Lakes. A letter grade from "*A*" through "*F*" indicates the quality of the shorelines of 17 ecoregions and 12 special ecological communities, whereas a

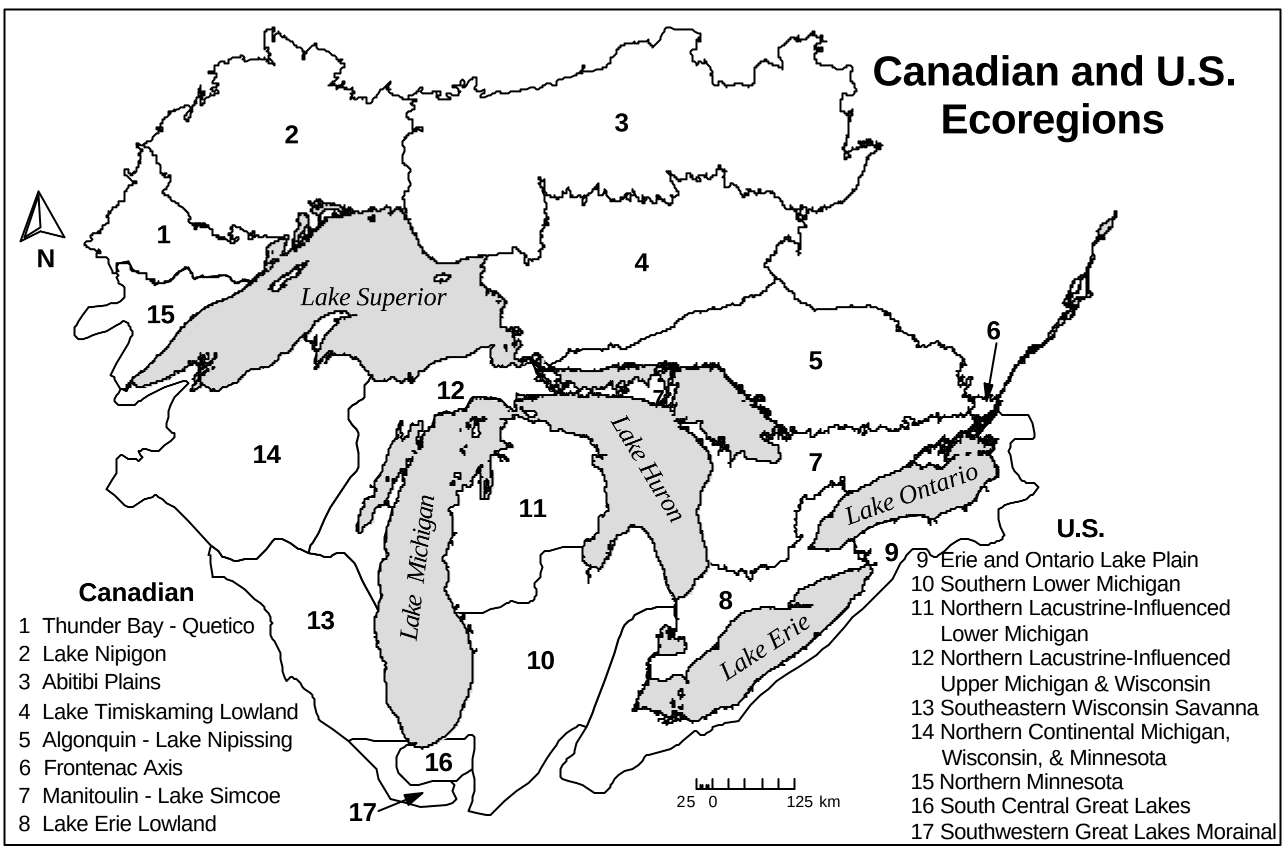

Figure 11. Great Lakes Coastal Ecoregions
Source: Reid, R. and K. Holland. 1997. *The Land by the Lakes: Nearshore Terrestrial Ecosystems.* (SOLEC 96 Background Paper)

scale from "*good*" to "*poor*" characterizes four elements regarding the status of individual Lakes.

5.3.2.1 Ecoregions

Ecoregions are large landscape areas defined by climate, physical characteristics, and the plants and animals living there. There are 17 ecoregions in the Great Lakes basin (Figure 11), each with a nearshore terrestrial component. The extent to which special ecological communities are represented and protected within each ecoregion, as well as the rate of land-use change affecting these communities determine the ecoregion ratings. Specifically, an assessment of the quality of ecoregional shorelines was based on the following categories:

- characteristic shoreline types
- significant natural communities
- existing representation in parks/protected areas
- priority unprotected features
- urban area within shoreline watersheds
- agriculture within shoreline watersheds
- residential/cottage/marina shoreline use
- lake edge armored against erosion
- rate of land-use change
- planning/restoration activities under way
- trend in shoreline health

Because of the varying nature of the ecoregions and their relationship with the Great Lakes, this approach to assessing the quality of shorelines works better in some regions than others. In the ecoregions along the north shore of Lake Superior, for example, land uses and stresses are fairly consistent across the coastal areas of each ecoregion. But in some of the more southerly ecoregions, particularly those that front on more than one Lakes, this degree of generalization may mask important internal differences.

There is some concern that the ecoregional ratings are overly generalized. Future refinements to this approach, perhaps using a more detailed ecodistrict scale and incorporating quantitative data wherever possible, would be valuable.

Only a few of the ecoregions have protection for areas that represent the full range of nearshore biodiversity; over half have seriously inadequate representation, with a trend of moderate to severe degradation of shoreline health (Table 6).

5.3.2.2 Ecological Communities

Special lakeshore ecological communities are places with unique physical features and habitats that support biodiversity or unique plant and animal life. The quality of 12 special lakeshore ecological communities (Table 7) was rated on the basis of the following:

- percentage of the community remaining in a healthy state
- major stresses
- sources of stress
- processes/functions impaired
- species/communities endangered/ threatened
- stewardship activities in place
- condition or trend (from no change or stable to severely degrading)

The first category, percentage remaining in a healthy state, is an estimate of the extent of each community remaining intact from its original, pre-European settlement, state. The other categories relate to current stresses, impacts, and activities, that affect the future of the special communities as they exist now. The condition or trend category relates to trends over roughly the past two decades. For many of the communities, trend information is incomplete, so the ratings have been assigned and reviewed by individuals knowledgeable in the field. A more complete analysis of the current and former distribution of these special lakeshore communities, trends affecting their

Table 6. The State of Nearshore Terrestrial Health in Great Lakes Ecoregions

Ecoregion	Lake(s) Bordered	Rating	Trend
Northern Continental Michigan, Wisconsin, & Minnesota	Superior	B	Stable
Northern Minnesota	Superior	B	Moderately degrading
Thunder Bay-Quetico	Superior	C	Moderately degrading
Lake Nipigon	Superior	B	Stable
Abitibi Plains	Superior	A	Stable
Lake Timiskaming Lowland	Superior	B	Stable
Northern Lacustrine-Influenced Upper Michigan & Wisconsin	Superior / Huron	B	Moderately degrading
Algonquin-Lake Nipissing	Huron	B	Stable
Manitoulin-Lake Simcoe	Huron / Ontario	D	Moderate-severely degrading
Frontenac Axis	Ontario	C	Moderately degrading
Lake Erie Lowland	Erie / Ontario	D	Severely degrading
Erie and Ontario Lake Plain	Erie / Ontario	D	Severely degrading
Southern Lower Michigan	Huron / Michigan	C	Moderately degrading
Northern Lacustrine-Influenced Lower Michigan	Huron / Michigan	B	Stable
South Central Great Lakes	Michigan	C	Severely degrading
Southwestern Great Lakes Morainal	Michigan	C	Severely degrading
Southeastern Wisconsin Savanna	Michigan	D	Severely degrading

Source: Reid, R. and K. Holland. 1997. *The Land by the Lakes: Nearshore Terrestrial Ecosystems.* (SOLEC 96 Background Paper)

future, and management needs would be very valuable.

Although most of these community types are undergoing some conservation activities, five communities are considered to be moderately or severely degrading. Shoreline alvars and lakeplain prairie communities are most at risk.

5.3.2.3 Lake by Lake Assessment

Each Lake is also assessed according to four indicators: retention of communities/species, retention of natural shoreline processes (un-armored shoreline), representation of biodiversity in lakeshore parks and protected areas, and gains in habitat protection in

Table 7. The State of Special Great Lakes Ecological Communities in the Nearshore Terrestrial Ecosystem

<table>
<tr><th>Special Ecological Community</th><th>Major Stress</th><th>Major Source of Stress</th><th>Overall Rating of Community Health</th><th>Trend</th></tr>
<tr><td>Sand beach</td><td rowspan="12">HABITAT ALTERATION</td><td rowspan="12">CHANGING LAND USE</td><td>C</td><td>Moderately degrading</td></tr>
<tr><td>Sand dune</td><td>D</td><td>Moderately degrading</td></tr>
<tr><td>Bedrock beach/cobble beach</td><td>D</td><td>Moderately degrading</td></tr>
<tr><td>Unconsolidated shore bluff</td><td>C</td><td>Moderately degrading</td></tr>
<tr><td>Coastal gneissic rocklands</td><td>C</td><td>Moderately degrading</td></tr>
<tr><td>Limestone cliffs/talus slopes</td><td>B</td><td>Moderately improving</td></tr>
<tr><td>Tallgrass prairies</td><td>F</td><td>Severely degrading</td></tr>
<tr><td>Sand barrens</td><td>D</td><td>Moderately degrading</td></tr>
<tr><td>Arctic-Alpine disjunct communities</td><td>B</td><td>Stable</td></tr>
<tr><td>Atlantic coastal plain communities</td><td>C</td><td>Moderately degrading</td></tr>
<tr><td>Shoreline alvars</td><td>F</td><td>Severely degrading</td></tr>
<tr><td>Islands</td><td>C</td><td>Moderately degrading</td></tr>
</table>

Source: Reid, R. and K. Holland. 1997. *The Land by the Lakes: Nearshore Terrestrial Ecosystems.* (SOLEC 96 Background Paper)

selected "biodiversity investment" areas (Table 8). With several exceptions, four of the Lakes are rated in the *mixed/deteriorating* or the *poor* category. Lake Superior receives a *good* rating in almost all categories.

Given the findings that existing protection and restoration programs are inadequate to meet the continuing stresses to habitat and physical processes, a conservation strategy for Great Lakes coastal areas is urgently needed. This strategy should seek to involve all levels of governments and other stakeholders, reflect commitments to biodiversity conservation and sustainable development, and secure broad support from Great Lakes citizens. It should place special emphasis on protecting large core areas of shoreline habitat within the 20 Biodiversity Investment Areas (Figure 17 in section 9). The Biodiversity Investment Areas are clusters of shoreline areas with exceptional biodiversity values that present key opportunities to create large protected areas that will preserve ecological integrity and, ultimately, help protect the health of the Great Lakes themselves.

Table 8. Indicators of Overall Ecosystem Health and Stressors for the Land by the Lakes

Lake	Indicators	Condition	Trend
Lake Superior	Retention of shoreline species/communities	Good	Stable
	Retention of natural shoreline processes (un-armored shoreline)	Good	Stable
	Representation of biodiversity in lakeshore parks & protected areas	Good	Improving
	Gains in biodiversity investment areas	Mixed	Improving
Lake Michigan	Retention of shoreline species/communities	Mixed	Deteriorating
	Retention of natural shoreline processes (un-armored shoreline)	Mixed	Deteriorating
	Representation of biodiversity in lakeshore parks & protected areas	Mixed	Stable
	Gains in biodiversity investment areas	Mixed	Improving
Lake Huron	Retention of shoreline species/communities	Mixed	Deteriorating
	Retention of natural shoreline processes (un-armored shoreline)	Mixed	Stable
	Representation of biodiversity in lakeshore parks & protected areas	Mixed	Improving
	Gains in biodiversity investment areas	Mixed	Deteriorating
Lakes Erie and St. Clair	Retention of shoreline species/communities	Mixed	Deteriorating
	Retention of natural shoreline processes (un-armored shoreline)	Poor	Deteriorating
	Representation of biodiversity in lakeshore parks & protected areas	Mixed	Stable
	Gains in biodiversity investment areas	Poor	Stable
Lake Ontario	Retention of shoreline species/communities	Mixed	Deteriorating
	Retention of natural shoreline processes (un-armored shoreline)	Poor	Deteriorating
	Representation of biodiversity in lakeshore parks & protected areas	Mixed	Stable
	Gains in biodiversity investment areas	Mixed	Stable

Source: Reid, R. and K. Holland. 1997. *The Land by the Lakes: Nearshore Terrestrial Ecosystems.* (SOLEC 96 Background Paper)

6. Stress on the Nearshore

As evidenced by the state of ecosystem health within the three geographical components of the Great Lakes nearshore, the nearshore ecosystem continues to be stressed by human activity. In particular, industrial, commercial, residential, agricultural, and transportation-related activities all have specific and cumulative impacts on the Great Lakes, their tributary waters, and nearshore areas. Table 9 illustrates the state of a number of land-use indicators. Due to their unique and sensitive environments, and their proximity to development Great Lakes nearshore areas bear the brunt of a disproportionate amount of environmental burden caused by human activity. This section examines the nature and source of this burden by focusing on the different types of stressors to which nearshore ecosystems are exposed: physical, chemical, and biological stressors.

6.1 Physical Stressors Including Land Use

Physical stress can do two things to ecosystems: it can directly alter habitat and it can disrupt the functioning of important physical processes that support the existence of the habitat. When a piece of land, shoreline, or lake bed is cleared or substantially modified for human use, most of the living and non-living components of ecosystems are destroyed. Some species cannot move or are not well-adapted to the altered or diminished habitat. These conservative species often require very specific habitat features, which sometimes include the presence of associated species. They tend to be relatively rare and the first to be lost when change occurs. Some species, however, have broader limits of tolerance and can continue to inhabit the area. Even these species can be relegated to tiny fragments of their original territory. Such habitat fragmentation makes it difficult or impossible for isolated individuals within a species to interact. As a result, the flow of genetic information that is necessary to sustain populations is inhibited.

The disruption of physical processes can also have a devastating impact on the health of ecosystems. For example, the presence of sand-starved areas along the Great Lakes shoreline is the result of human development activities that interrupt the natural sediment nourishment process. Shoreline hardening, breakwaters, bridges, and other artificial coastal structures are examples of developments that prevent or accelerate the erosion of sand in some places, and prevent the deposition of sand in others.

Development in all its forms is a leading stressor of the Great Lakes basin ecosystem and, in particular, the nearshore area. Large-scale population settlement and development have gone hand in hand in the Great Lakes nearshore ecosystem resulting in decades of physical stress. Today that development continues. The most significant development issue in the Great Lakes basin and surrounding region is the continuing growth of major metropolitan areas, coupled with growth of smaller urban centers and development of recreational areas. Not only are urban areas growing in population, but the way they are growing has changed over time. The central city anchor for rail transportation, multi-story factories, and apartment life has given way to

Table 9. Land-Use Indicators

Desired Outcome	Indicators	Condition of Stressor	Trend
Efficient Urban Development	Urban population density	Poor	Stable
	Suburban land conversion	Poor	Deteriorating
	Center-town economy (based on fiscal condition, vacancies, etc.)	Mixed	Deteriorating
	Brownfields (number & area)	Poor	Stable
	Recreation opportunities (number & area of parks)	Mixed	Improving
	Energy use (per capita)	Poor	Improving
	Waste created (residential & industrial)	Poor	Improving
	Wastewater quality (based on nutrient & toxic loadings)	Mixed	Improving
	Industrial water use	Mixed	Improving
	Residential water use	Poor	Stable
	Traffic congestion	Poor	Deteriorating
	Transit use	Poor	Deteriorating
Protection of human health	Air pollution levels (based on particulates & ozone levels)	Poor	Improving
	Beach closings (number of unswimmable days)	Inadequate data	Unknown
	Land-fill capacity	Mixed	Stable
	Stormwater quality (based on nutrient & toxic loadings)	Poor	Stable
	Sewage quality (based on nutrient & toxic loadings)	Mixed	Improving
	Pollution-prevention programs (industrial & municipal programs)	Mixed	Improving
	Respiratory illness (based on hospital admissions & death records)	Mixed	Stable
	Fish advisories	Mixed	Improving
	Outdoor recreation (based on opportunities & participation)	Mixed	Improving
Protection of resource health	Wetland habitat (number & area)	Mixed	Deteriorating
	Agricultural & natural land loss (area lost to rural development)	Poor	Deteriorating
	Wildlife populations	Mixed	Stable
	Forest clearing (based on cutting rates), replanting & renewal	Mixed	Stable
	Mineral extraction	Mixed	Stable
	Fishing pressure	Mixed	Deteriorating
	Hunting pressure	Good	Stable
	Hardening of land surface (based on area of roads & buildings)	Poor	Deteriorating
	Municipal pesticide/fertilizer use	Poor	Stable
	Agricultural pesticide/fertilizer use	Mixed	Improving
	Conservation tillage	Mixed	Improving
	Groundwater quality (based on area/number of contaminated wells)	Mixed	Deteriorating
	Contaminated sites (area and number)	Mixed	Improving
	Cottage & second homes (number per coastal area)	Poor	Deteriorating

Source: Thorp, S., R. Rivers, and V. Pebbles. 1997. Impacts of Changing Land Use. (SOLEC 96 Background Paper) truck and auto transport, one-story industrial buildings, sprawling office parks, and expansive suburban residential areas.

An example of this expansion can be seen in northeastern Illinois, where the overall population of the six-county area increased only 4.1 percent from 1970 to 1990; however, land consumption increased by an estimated 46 percent. Natural areas as well as agricultural areas (together identified as “greenfields”) are prime targets for this development. For example, in Michigan, farmland was converted to some other use at the rate of 4 hectares (10 acres) an hour in the decade between 1980 and 1990. If significant levels of farmland conversion continue in the Great Lakes basin, the agricultural production base will decline and, along with it, the agri-food sector of the economy.

One of the factors driving the movement of industry away from urban areas is the problem associated with redeveloping sites on which manufacturing operations once thrived. The Great Lakes basin contains thousands of former industrial sites (known as “brownfields”) that have been abandoned because of cleanup costs and lingering liability associated with the development of lands, which, in many cases, are sources of continuing toxic pollution. Although there is no comprehensive inventory of brownfield sites in the Great Lakes basin, the amount of land categorized as such is large—possibly tens of thousands of acres. Much of this land could potentially be developed for relatively high-density uses. While the amount of land being absorbed in current sprawl development is far larger, redevelopment of brownfields could contribute significantly to efficient and sustainable urban development.

It is reasonable to assume that development activities will continue to physically stress nearshore ecosystems because the responsibility for land-use decisions that affect the ecosystem is fragmented among a very large number of government entities.

Government jurisdictions within the basin include two federal governments; one province and eight states, each with a myriad of agencies; 13 regional and 18 county municipalities in Ontario, many regional planning commissions and councils of government, and 192 counties in the U.S.; thousands of U.S. local governments and about 250 Canadian local governments; and more than 100 First Nations and tribal authorities. In addition, significant influence is brought directly to the development approval process by private sector developers and consultants, non-profit organizations such as environmental groups and residents’ groups, the media, and the public. The greatest degree of decision-making authority regarding land use rests with local governments.

A different kind of physical stress is created by thermal-electric power plants, which cause substantial fish mortality. Most of the power in the Great Lakes basin is produced by these plants, which use large volumes of water to cool and condense steam in the power generation cycle. About 90 thermal-electric plants draw their cooling water directly from the nearshore waters of the Great Lakes and use a once-through cooling process. The water is first drawn through screens and then passed through the plant’s heat exchangers, where a temperature increase of between 4° and 20° Celsius occurs before the water is discharged into the Lake. Fish that are small enough to pass through the entry screens are drawn into the plant with the cooling water. They are then killed either by colliding with other screens and surfaces in the system or by heat shock. Fish that are too large to pass through the screens are caught on the screens and killed. Research in the early eighties indicated that thermal-electric power plants in Lake Michigan killed more than 75 billion fish eggs and larvae annually. A single pumped-storage hydro plant on the Lake’s eastern shore killed more than 400 million fish larvae and more than 100 million juvenile alewife, yellow perch, and salmon annually. While efforts continue to be made to mitigate the negative impact of these plants on Great Lakes fish populations, the plants remain a stress on the nearshore ecosystem.

The final physical stress to be mentioned in this report is an emerging concern not only to those living in the Great Lakes basin but to human populations around the world—namely, climate change and variability. Mathematical models suggest an average warming of 3° to 8° Celsius for the Great Lakes basin (depending on the season and the location) by the latter half of the next century. The greatest impacts are expected to be indirect changes in other climate conditions, not just temperature change. Rainfall patterns, soil moisture, evapotranspiration, snow-season length, extreme heat, and the frequency and severity of weather disasters such as thunderstorms, hail, and tornadoes are all expected to change regionally. The most profound direct impact would be on the hydrological cycle. Consequences could include a decline in the overall basin water supply of 2 to 113 percent, a subsequent decline in outflow to the freshwater portion of the St. Lawrence River basin of 20 to 40 percent, a decline in groundwater recharge rates, an increase in evaporation rates leading to increases in the frequency and severity of drought conditions, and a shift in both terrestrial and aquatic species as those dependent on cooler climates move north. Climate change and variability may have consequences for agriculture, forestry, and urban infrastructure within the basin.

In the past, studies have focused on water quality; however, with climate change and variability, water quantity in the basin may become an increasingly important issue. Mean water levels could be reduced on all the Great Lakes. This would therefore affect the regulation of water levels on Lake Ontario. Lower water levels would also disrupt Great Lakes coastal wetland ecosystems. Less water may lead to poorer water quality, since dilution of point source contaminants would not be as great; and the relative importance of contaminants originating from other sources (rainfall, groundwater, surface flow, or release from lake sediments) would be modified.

Figure 12 illustrates the potential impact of one climate change scenario on Lake St. Clair water levels. The volume of Lake St. Clair could be reduced by 37 percent and the surface area could decrease by 15 percent. These water-level declines may displace the shoreline by as much as 6 kilometers (4 miles) from its present location, exposing large areas of lake bottom. This would adversely affect wetlands, marinas and recreational boating, commercial navigation, and public water supply intakes.

Climate change models predict progressive, linear changes through time. However, ecosystem response is most likely to be non-linear, with an apparent resistance to change up to a certain threshold, beyond which a rapid (and possibly catastrophic) transition may occur. It is important for managers to understand this and assess the amount of stress an ecosystem can sustain before it is irretrievably damaged. Assessing ecosystem health with respect to climate change is complicated by our lack of understanding of the effects of previous human interventions. Ecosystems have already been considerably altered by the cumulative effects of water-level regulation, pollution, introduction of exotic species, and resource exploitation, to name a few. These effects may decrease our ability to detect changes caused by climate change and variability.

6.2 Chemical Stressors

The large algal mats that dominated Lake Erie waters during the sixties and seventies have disappeared with the introduction of, and adherence to, strict phosphorus-loading targets. Although control programs have generally reduced nutrient concentrations in the Lakes, high concentrations can still occur locally in embayments and harbors, arising

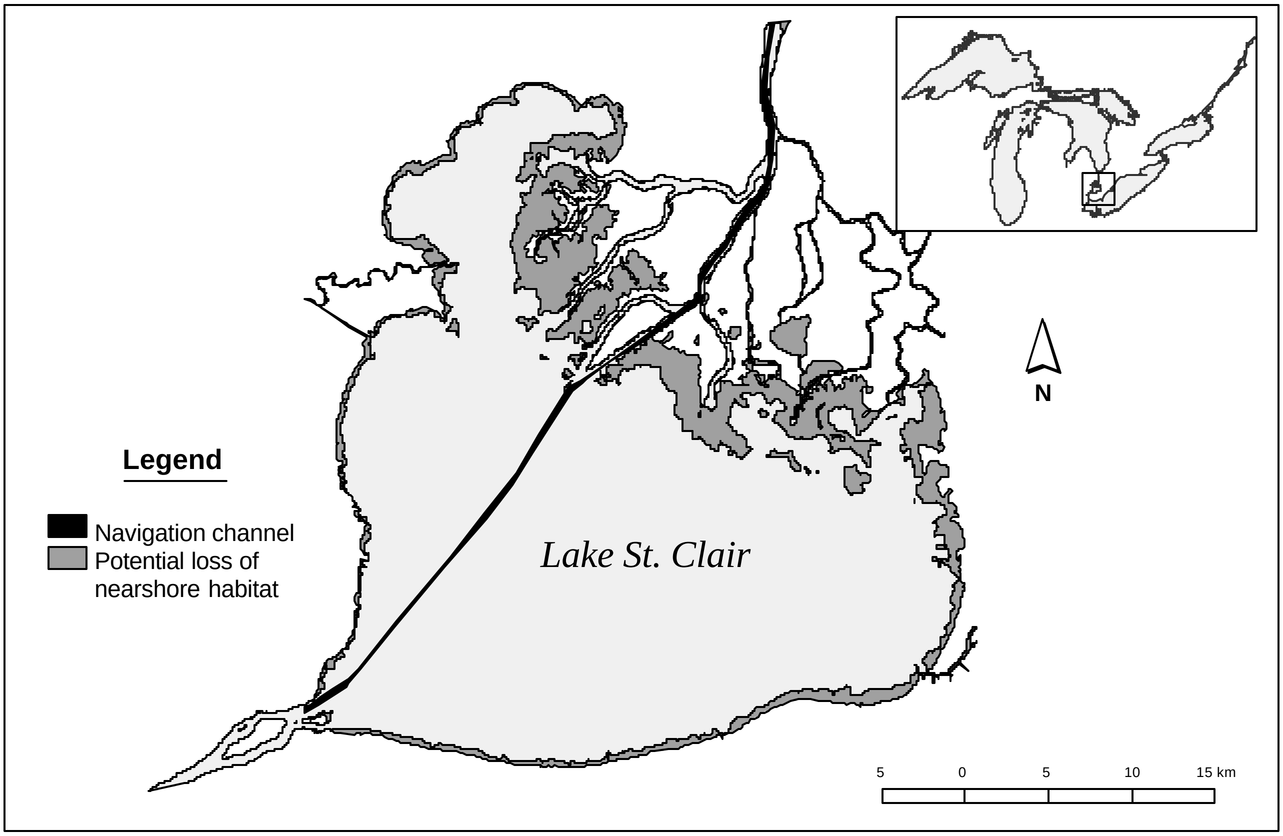

Figure 12. Potential Loss of Nearshore Habitat in Lake St. Clair (due to a lowering of Lake levels) as a Result of Climate Change, Based on a Doubling of Carbon Dioxide
Source: Lee, D., R. Moulton, and B. Hibner. 1996. *Climate change impacts on western Lake Erie, Detroit River, and Lake St. Clair water levels*, report prepared for the Great Lakes-St. Lawrence Basin Project, 51pp.

from agriculture and urban sources (Figure 13). Excessive algal growth due to high nutrient concentrations leads to algal decomposition and oxygen depletion. A shift in the makeup of the ecological community then follows, favoring species that benefit from excess nutrients, reduced oxygen, and the reduced sunlight and visibility conditions that are generated by excess algal growth.

The impact of persistent toxic contaminants is less visible and often shows no effect until the contaminants are concentrated in the food chain, beginning with algae and zooplankton. Through the processes of biomagnification and bioaccumulation, the impact of toxic chemicals is greatest on animals at the top of the food web such as predatory birds, fish, and mammals, including humans. Effects seldom result in acute symptoms or death at any level within the ecosystem, but they include impaired reproduction and reduced resistance to disease. Toxic chemicals enter the nearshore ecosystem via a number of routes, including atmospheric deposition, pesticide use, industrial discharge, municipal discharge, storm runoff, and leaching from contaminated sediments from both on shore and underwater.

Pesticides are an important part of Great Lakes basin agriculture. These chemical compounds are widely used for the control of weeds, insects, and diseases that can reduce production. The risk to wildlife and human health of pesticide exposure is a matter of public concern, and continued scientific

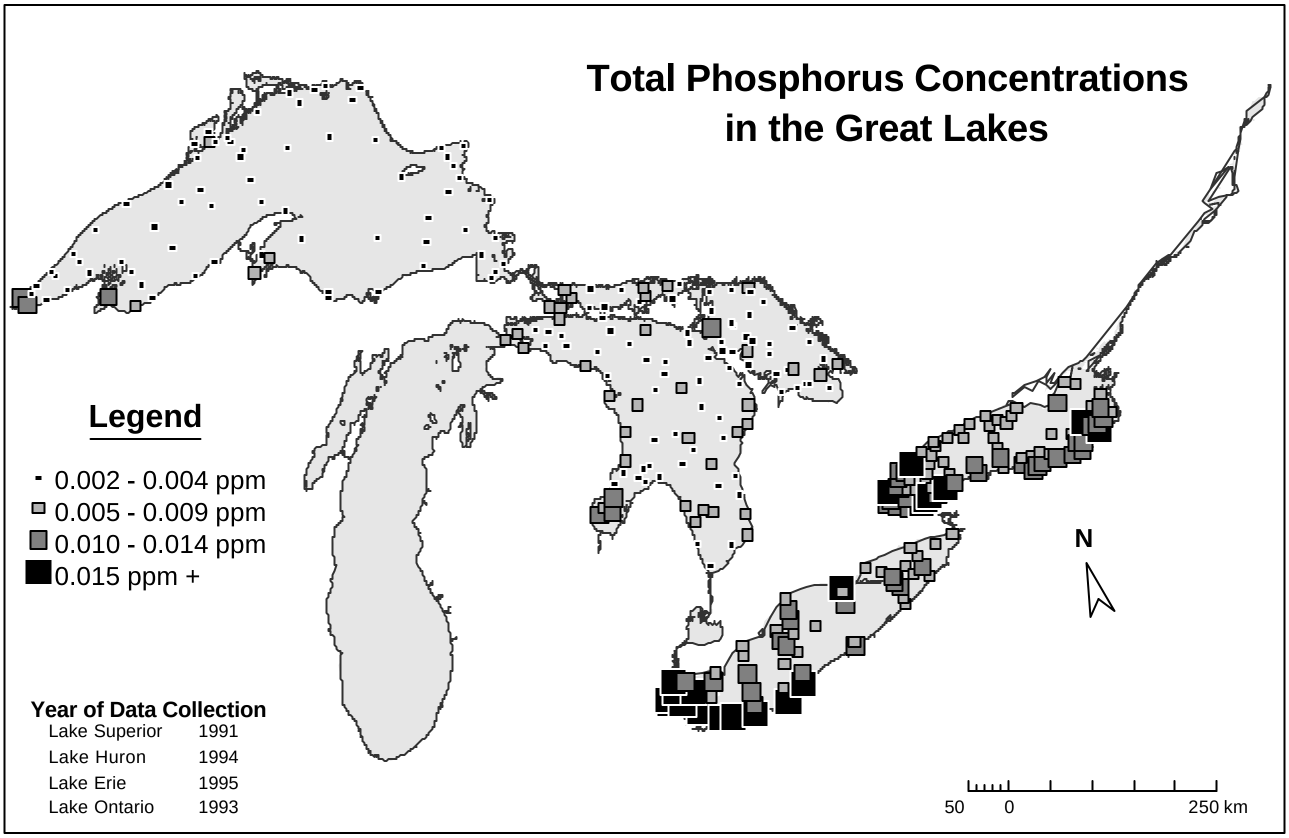

Figure 13. Total Phosphorus Concentrations in the Great Lakes

Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)

research is necessary to characterize the nature of any risk and help devise effective and safe formulations and methods of use. According to a report prepared by the World Wildlife Fund, agriculture in the Great Lakes basin uses an estimated 26 million kilograms (58 million pounds) of pesticides annually. Herbicides represent about two-thirds of the pesticides applied, with corn and soybeans receiving much of this amount. These herbicides must be present in high concentrations to be toxic to animals, but can affect aquatic plants at lower levels. Direct toxicity due to short exposures at high concentration would be more likely to occur in headwater reaches; whereas effects due to chronic (longer-term at somewhat lower levels) exposure would be more likely in the lower reaches and in the nearshore waters.

The atmosphere is also an important and sometimes predominant pathway for toxic contaminants to the Great Lakes. The very nature of the Great Lakes contributes to the intensification of air-quality problems caused by the industrial and urban heartland around the lower Lakes. Emissions from cars and trucks using the road network inside as well as outside the Great Lakes basin are a significant source of atmospheric pollutants. Pollution sources of local atmospheric toxic substances are fairly well-understood and are being subjected to continuing abatement efforts. However, as development around the Great Lakes increases the number of local roadways and traffic density, air quality declines. Although 25-year trends in Ontario’s air quality show significant decreases in average levels of a number of compounds (lead, carbon monoxide, sulphur dioxide, total sulphur particles, nitrogen oxides), ozone pollution has increased. Ozone, a by-product of nitrogen oxide pollution, is a powerful lung irritant.

Local concentrations of ground-level ozone and acid aerosols can be significantly higher near the shorelines compared with those measured at sites well inland. During the warm season, the relatively smooth and cold surfaces of the Great Lakes interact in varying fashions with the air pollutants that move into the basin or are produced locally. Ground-level ozone tends not to deposit on lake waters, so it travels further than would otherwise be the case. On the other hand, airborne ammonia, which normally neutralizes acid aerosols, dissolves so well on the surface of water that acid aerosols tend to persist longer. The Great Lakes also develop local lake breeze circulations, which can confine pollutants and under the right conditions cycle them around the lake shorelines. This limits dispersion and creates a “pressure cooker” effect in which greater concentrations of smog can form in urban plumes.

In Ontario, the highest concentrations of ground-level ozone are measured not immediately downwind of cities as might be expected, but at Long Point on the Lake Erie shoreline, followed by stations near Lake Huron. During smog episodes, acid sulphate concentrations near Lake Erie have been measured at more than twice the concentrations observed inland, coupled with the high levels of ozone. A similar pattern occurs around all of the Great Lakes south of Lake Superior; however, it is diminished by distance from the main sources and modified by the way the shoreline interacts with the large-scale wind pattern.

This local pollution intensification is due to the very existence of the Lakes and cannot be changed. Abatement measures that would produce adequate results at inland sites may be insufficient near the shores or over the Lakes. Work is under way to understand the situation better through enhanced meteorological models. Additionally, the potential health impacts must be properly assessed and communicated to the public. People may have to be advised that the summer air on a beach or in other recreational areas can be worse than it would be in the city.

Nearshore regions encounter atmospheric stresses which are most severe at local scales, near urban areas for example. However, atmospheric pollutants may be deposited on the Lakes from sources large distances away from the Great Lakes basin due to long-range transport. Toxaphene, for example, has been seen to arrive from areas in the southern U.S. and Mexico where it was widely used in the past (Figure 14). Five-day back trajectories are shown for the five highest air concentrations of toxaphene measured at Egbert, Ontario, during a one year study in 1988/9. These air trajectories arise from regions which have known high historical use patterns as indicated by the tonnages shown. This indicates that toxaphene is still arriving in the Great Lakes basin some ten years after its usage was banned and points to the existence of the ‘grasshopper effect’, the revolatilization and redeposition of old use pesticides. For many past-use chemicals which are now banned or restricted in North America, residual re-emissions can be important sources of contaminants to the lakes.

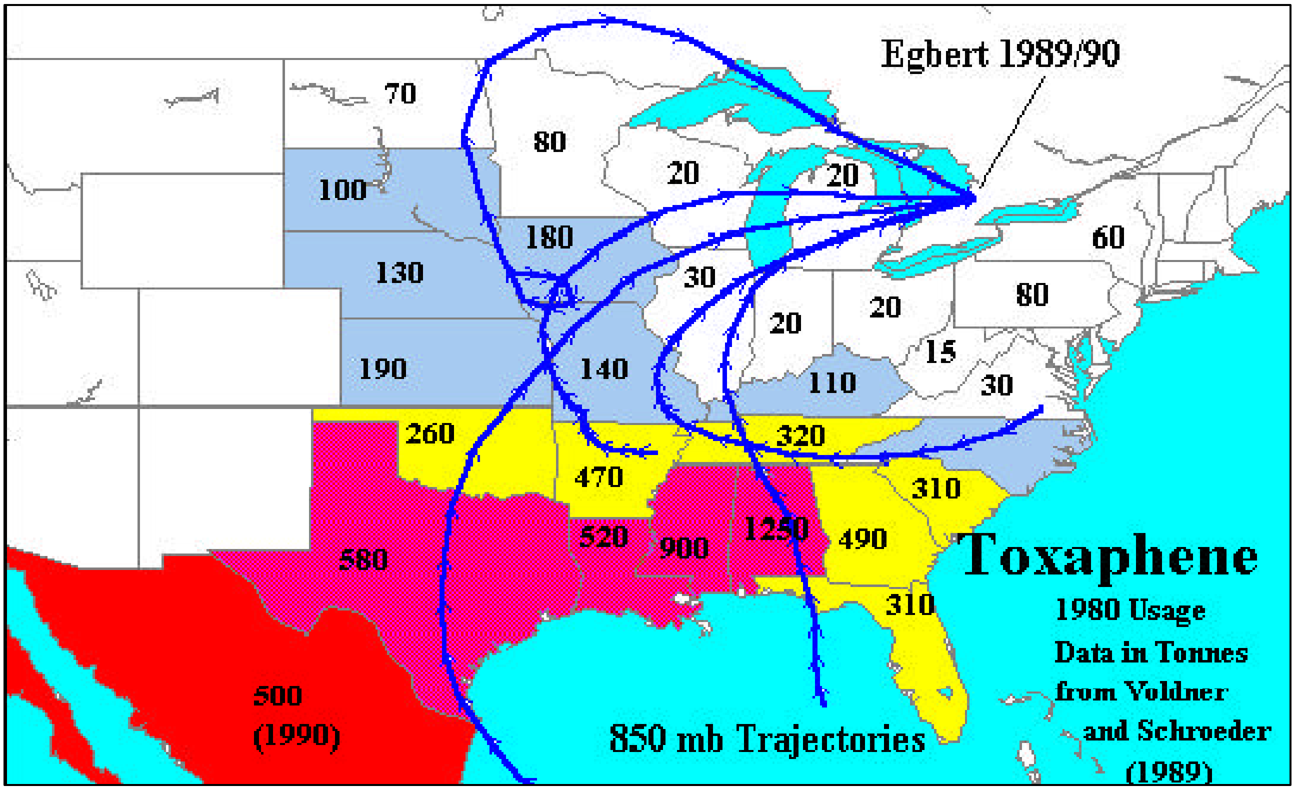

Figure 14. Five-day back trajectories for toxaphene measured at Egbert, Ontario.
Source: Hoff, R., D. Muir, N. Grift, and K. Brice. 1993. *Measurement of PCCs in Air in Southern Ontario*, Chemosphere, 27, 2057-2062.

6.3 Biological Stressors

In terms of biological stress, the global transfer of exotic organisms is one of the most pervasive and perhaps least recognized effects of humans on the world's aquatic ecosystems. As illustrated earlier in this report, such transfers lead to loss of species diversity and to extensive alteration of native communities. Decline and loss of species and genetic diversity are critical aspects in the loss of ecosystem integrity and the ability of ecological communities to remain resilient during times of environmental change. Genetic diversity within species improves the odds that at least some members of the population will have the genes needed to survive a particular environmental change.

Exotic species have affected the Great Lakes aquatic ecosystem since the early 1800s. At least 139 new organisms have become established—42 percent are plant species, 18 percent are fish species, and 17 percent are algae species. The remaining 22 percent are made up of a variety of species, including mollusks, crustaceans, and disease pathogens.

It is useful to distinguish between the forces that introduce exotic species into the Great Lakes. Some exotic species are introduced into the Great Lakes intentionally, for example, the stocking of some non-native fish species into the Lakes such as Pacific salmon, rainbow trout, and brown trout; many more are introduced unintentionally. Shipping activities alone are responsible for bringing 41 exotic aquatic species to the Great Lakes, of which 63 percent arrived in ballast water, 31 percent with solid ballast, and 6 percent on ship hulls. Unintentional releases established 40 new species in the Great Lakes, 30 percent of which were plants that escaped from cultivation. Unintentional releases also include accidental release from fish culture activities (19 percent) and aquarium holdings (17 percent). Seventeen organisms entered the Great Lakes through canals, along railroads or highways, or as deliberate releases.

Not all exotic species are invasive and disruptive. Many are unable to compete with native species or simply exist in balance with native species. Some exotic species, however, are invasive and destructive of native species and communities. Invasiveness is usually associated with unusual competitive advantage, which may have evolved in the place of origin or result from the absence of predators or diseases of the organism in the new location. Moreover, native species need time to adapt to competition from newly arrived organisms. This may, however, take a very long time, and the native species may be unable to adapt. Each exotic species exists as a natural component of a natural ecosystem in the waters of its homeland. In a new location, it may be free of the natural checks established through long periods of evolutionary development and be able to invade and take over large areas. As they do, they cause drastic changes to food chains and habitats that are essential to our native plant and animal communities.

An additional factor in the rapid spread of invasive exotic species is the disruption of the habitats that support native species. Natural disturbances are a normal part of the ecosystem and are important to its long-term balance. However, human development of agriculture, industry and communities causes disturbance of large-scale areas in relatively brief time frames, which do not allow the native species and biological communities to adapt. Changes in hydrology, water chemistry, and water temperature are examples of disturbances that have favored exotic species.

Another category of biological stress is excessive harvest of renewable resources. This directly affects biological integrity and can also create conditions favoring invasive exotic species. Exotic species compete for nutrients and space with native species, often moving in when an ecosystem has been disturbed and before native species have time to recover. For example, excessive harvesting caused the depletion of top native predator fish in the Great Lakes, paving the way for explosive growth of non-native alewife populations. Another invasive fish species is carp, which may have been aided by depletion of lake sturgeon. The lake sturgeon, which does not reproduce until it is about 25 years old, was one of the first species to fall victim to this type of stress. Annual catches in Lake Erie's U.S. waters fell from an all-time high of 2.1 million kilograms in 1885 to about 13,000 kilograms in 1917. Thereafter, reported catches never exceeded 10,000 kilograms, and after 1966, the catch fell to zero. Increased awareness of the consequences of overfishing, has led to fisheries management efforts to avoid the recurrence of such devastation to other Great Lakes fish populations.

One final example of biological stress on the nearshore ecosystem is microbial contamination (micro-organisms include bacteria, fungi, microscopic algae, protozoa, and viruses). The human population in the Great Lakes basin produces large amounts of liquid wastes (sewage), which must be rendered harmless by processes in sewage treatment plants. In spite of technology that makes it possible to perform high levels of sewage treatment, large amounts of pollutants are still discharged into Great Lakes waters. This is especially true in areas that have combined sanitary and storm sewer systems. Storm drains are fed into the same pipes that carry household sewage and industrial wastes. Combined systems saved costs for municipalities at the time of construction because separate sanitary sewers were not built. However, the greater volume that the sewers are required to carry during periods of heavy rainfall or snowmelt frequently exceeds the capacity of the system, causing overflow that bypasses the treatment plant and discharging untreated sewage into the receiving waters. Wastes from farm animals and even wildlife can also be sources of pathogens.

7. Lake by Lake

As described in the 1995 State of the Great Lakes report, climate, soils, and topography vary widely throughout the Great Lakes basin. In the north, the climate is cold, and the terrain dominated by a granite bedrock known as the Canadian (or Laurentian) shield. Coniferous forests dominate the vegetated landscape, growing on a generally thin layer of acidic soils. In the south, the climate is significantly warmer, and the terrain flatter with clay, silt, and sand, forming many fertile areas mixed in places with gravel and boulders. These differences in physical form represent only the first in a long list of factors that make each Great Lake unique. Plant species differ; animal species differ; and the concentration of human settlement varies widely throughout the basin. From the relatively low-density populations along the northern coast of Lake Superior to the high-density areas found in coastal cities such as Toronto and Chicago, humans play a large role in dictating nearshore ecosystem health on each Lake.

Using the following words in the statement of purpose in the Great Lakes Water Quality Agreement, the U.S. and Canada agreed to protect their shared treasure: " to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." The Agreement contains many provisions to accomplish this, but a key aspect is the commitment to coordinate restoration of beneficial uses. A major component of this is the development of plans at two geographic scales. For designated geographic Areas of Concern (AOCs), where beneficial uses are impaired, there are Remedial Action Plans (RAPs). At the lakewide scale, Lakewide Management Plans (LaMPs) are being developed to address restoration of beneficial uses.

The U.S. and Canadian governments are working cooperatively to restore each of the remaining 42 (of the original 43) AOCs, so identified because one or more of 14 beneficial uses have been impaired. Local involvement is integral to the success of the remediation effort, and communities throughout the basin are working together in the cleanup process (through RAPs) to restore and protect environmental quality in these areas. There are 11 AOCs on the Canadian side of the Lakes, 26 AOCs on the U.S. side of the Lakes, and 5 AOCs in connecting channels (Figure 15).

Restoration of beneficial uses within the AOCs is the primary mission of RAPs and is an essential step in restoring the integrity of the Great Lakes basin ecosystem. Many of these AOCs have received decades of abuse. Identifying the problems, and planning and implementing the remedial strategies necessary to restore the beneficial uses in these areas can also take many years. One AOC, Collingwood Harbour, Ontario, has had its beneficial uses restored and is no longer listed as an AOC. The status of the beneficial use impairments for the AOCs is shown in Figure 16 (on pages 68-69).

LaMPs for Lakes Ontario, Erie, Michigan, and Superior are currently being developed. Individual LaMP programs are unique to each Lake and designed to deal with the issues and concerns of the agencies and publics involved. LaMPs are broader in scope than RAPs and can plan for lakewide load-reduction targets that have not been specified by RAPs. A LaMP for Lake Huron is scheduled to begin in 2000.

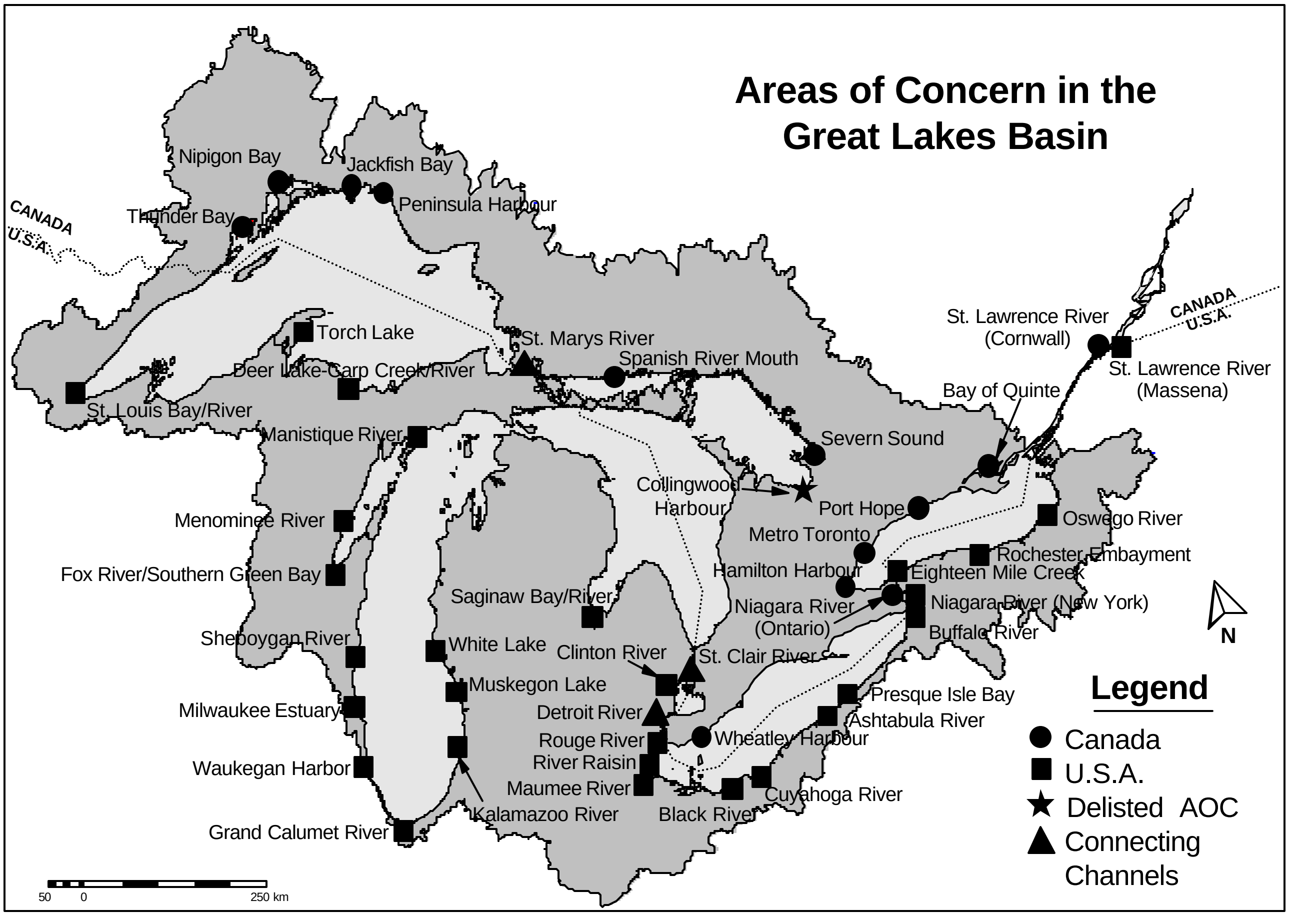

Figure 15. Areas of Concern in the Great Lakes Basin
Source: Geomatics Unit, Environment Canada, Ontario Region.

All the Lakes have some restrictions on fish consumption in order to protect the health of humans. Indicator species for coldwater fish include lake trout, and for warmwater fish, smallmouth bass, walleye, and yellow perch.

The following sections of this report take a closer look at the nearshore ecosystems in Lakes Superior, Michigan, Huron, Erie, and Ontario.

7.1 Lake Superior

Lake Superior is the deepest (with an average depth of 147 meters, or 483 feet)[2], the coldest, and the cleanest of the Lakes in the Great Lakes ecosystem. It has the largest surface area of any freshwater lake in the world, encompassing 82,100 square kilometers (31,700 square miles), and a shoreline of 4,385 kilometers (2,726 miles). The Lake also holds more water than all the other Great Lakes combined and ranks third in volume when compared with all other freshwater lakes on Earth.

[2]All length, depth, area and volume references in section 7 of the 1997 State of the Great Lakes report are from the following source: United States Environmental Protection Agency and Government of Canada. 1995. *The Great Lakes: An Environmental Atlas and Resource Book*. ISBN 0-662-23441-3. Chicago, Illinois and Toronto, Ontario.

Because of the Lake's large surface area and position at the headwaters of the Great Lakes ecosystem, rain and snowfall represent the largest sources of water to the Lake. The 335 tributary rivers and streams that drain into the Lake from the surrounding watershed represent the second largest source of water. Canada's Nipigon River is the largest tributary entering the Lake, and the second largest is the St. Louis River, which enters the Lake at Duluth. Water leaves the Lake through evaporation and regulated discharge via the St. Marys River. One result of this combination of physical characteristics is that a drop of water entering the Lake tends to stay in the Lake for a long time—between 173 and 191 years. This is also known as retention time.

The geology of the Lake Superior watershed is dominated by the outcrops of the Canadian Shield, rocks from the most ancient portions of the North American continent. These durable rocks form the northern Minnesota and Canadian shorelines, which are typified by prominent cliffs and rocky coastlines. Southern shore areas exhibit relatively well-developed beaches, dune fields, and wetland environments.

Development pressures are not as intense in the Lake Superior basin as they are in the other Great Lake basins, and the land-use activities in the Lake basin have had a relatively low impact on Lake Superior's nearshore ecosystem. Approximately 95 percent of Lake Superior's 127,700 square kilometer (49,300 square mile) drainage basin is forested, and the remaining 5 percent is split between agriculture, urban/industrial, and other land uses. With less than 2 percent of the entire Great Lakes basin population (approximately 610,000 residents), the Lake has been able to avoid many of the problems that go hand in hand with population pressures.

Forestry, mining, shipping, and tourism/ recreation are the four industries that form the mainstay of economic activity in the region. Residents of the Lake Superior basin have been affected by a long-term economic decline, and the result has been migration out of the basin. In 1970, 680,000 people lived within the basin, but by 1990/91, 70,000 people had left. On the U.S. side of the Lake, the relatively poor economic health of the area is reflected in depressed wage levels and an unemployment rate that is above the state average. The economy of the Canadian side of the basin is somewhat stronger, but is still weaker than in the rest of the province. However, despite the relatively weak basin economy and overall population decline, two significant trends are distinguishable: (1) Populations are expected to increase in the two largest urban areas within the basin, Duluth-Superior and Thunder Bay (both of which have strong local economies). (2) The number of second-home residents in the basin is rising, bringing both opportunities and challenges.

Although Lake Superior is relatively clean, there are localized hotspots where point source pollution has had an impact on the ecosystem. The seven AOCs identified on the Lake are Peninsula Harbour, Jackfish Bay, Nipigon Bay, Thunder Bay, St. Louis River, Torch Lake, and Deer Lake. Non-point source pollution deposited from the atmosphere is a proportionately large source of pollution in Lake Superior, and it has been determined that non-point sources actually have a bigger influence over nearshore water quality in the Lake than do point sources. For example, atmospheric sources account for 93 percent of total mercury loadings and 98.8 percent of PCBs.

There are consumption advisories for coldwater fish species, but these occur mainly with respect to the fish from the eastern end of the Lake (in the open waters from Sewell Point to Batchawana Bay), as well as in the waters of Thunder Bay's outer harbor. The principal contaminant causing these consumption restrictions is toxaphene, and dioxins are a concern in specific locations, such as Jackfish Bay. Although information on contaminants in indicator species is available only for certain sites, the only restriction on consumption of warmwater species relates to the walleye from Schreiber Point to Sewell Point. The contaminant causing the restriction is mercury.

In Lake Superior, the lake trout fishery is now maintained through natural reproduction of wild fish. This represents the first successful rehabilitation of lake trout stocks in the Great Lakes. Lake whitefish are abundant and support a productive fishery. Lake herring numbers are recovering strongly, whereas brook trout and lake sturgeon populations have not recovered from earlier declines and are still at low levels. Introduced species of trout and salmon support a stable fishery, but rainbow smelt are reduced from earlier levels of peak abundance.

Overharvesting is only one factor causing fish populations to decline. Exotic species such as sea lamprey and ruffe also contribute to the decline. Sea lamprey have been reduced to about 10 percent of their former peak abundance through the sea lamprey control program, thus saving some stocks of lake trout in Lake Superior. However, sea lamprey require continual control in order to increase or even sustain lake trout populations. Ruffe is an exotic fish species that has no commercial or sports value. It was introduced into Duluth Harbor from the ballast water of transatlantic cargo vessels. The ruffe has steadily spread through the nearshore waters, is increasing in abundance, and competes with perch and other native species for food and habitat.

Lake Superior's coastal wetlands are in comparatively good condition. Although there are no comprehensive estimates of coastal wetland losses for Lake Superior, it is clear that coastal wetlands on the Lake are comparatively less affected by human stressors than those of the other Great Lakes. Some local areas are degraded and regulation of lake levels is having some negative effect lakewide.

The north shore of the Lake is a high energy environment with few areas of sediment deposition. As a result, coastal wetlands are rare, and those that do occur are restricted to the large sheltered embayments of Goulais Bay and Batchawana Bay in the northeast, and Thunder Bay, Black Bay, and Nipigon Bay in the northwest. To date, approximately 915 hectares (2,287 acres) of coastal wetlands have been evaluated for quality in Canada; but at least 3,500 hectares (8,750 acres) have not.

Along the southern shore of Lake Superior, coastal wetlands are larger and more numerous than those found along the north shore. The shoreline is more complex, and many river mouths provide shelter from wind and wave action, thereby allowing wetlands to develop. Coastal wetlands occupy a total of 21,357 hectares (53,393 acres) along the south shore of Lake Superior. In Wisconsin, many large wetlands remain in relatively pristine condition, the largest of which is the 3,850 hectare (9,510 acre) Chequamegon wetland on the Bad River Indian Reservation. Lakewide, 41 fish species have been identified that use coastal wetlands for spawning, nursery, and feeding habitats.

Water-level regulation is the most widespread stressor on coastal wetlands on Lake Superior; however, other stressors affect wetlands on a site-specific basis. Nutrient enrichment, toxic contamination, recreational use, and shoreline development all act as site-specific stressors to coastal wetlands located on the Lake.

The health of Lake Superior's nearshore terrestrial ecosystems is better than the health of the other four Lakes, and fewer shoreline species and communities have been lost than in the other Lakes (see Table 8). Shoreline development activities are limited (because of lower population levels as well as the fact that the coastal substrate is primarily bedrock and cobble shore); therefore, shoreline processes are not as extensively interrupted by armoring as is the case with other Lakes. A good representation of Lake Superior's nearshore terrestrial biodiversity can be found in the lakeshore parks and protected areas. Progress has been made in protecting areas of particularly high biodiversity through the creation of new parklands or other protected areas, the development of land-use policies that will result in improved protection of the significant elements within these priority areas, and private stewardship initiatives. This progress has been rated as *mixed/improving* in the background paper "Land by the Lakes: Nearshore Terrestrial Ecosystems."

7.2 Lake Michigan

Lake Michigan is the only Great Lake entirely within the U.S. The Lake and its basin's land area are each the third largest of the Great Lakes and their basins, respectively. It is the fourth largest freshwater lake in the world in terms of area, and the fifth largest in terms of volume. Water retention time in the Lake is estimated at approximately 100 years, and the average depth in the Lake is 85 meters (279 feet). Census data for 1990 indicate a basin population of just over 10 million, most of which is located in the densely populated southern portion of the basin.

Lake Michigan may be the most diverse of any of the Lakes. Its shoreline changes continually from one major landform to another, with each major type extending for hundreds of miles. It has lakeplains, high clay bluffs, low erodible bluffs, vast dune fields, rocky cliffs, glacial drift bluffs, sand ridge shores, and clay/pebble embayments flanked by ancient ridges. Landforms in the basin vary from relatively high relief areas in the northwest to low relief plains in the central and southern portions of the basin. One of the most impressive features of the basin's nearshore is the expanse of sand dunes along parts of the eastern shore. Lake Michigan coasts also contain about 40 percent of all U.S. Great Lakes coastal wetlands, which are equally as diverse as the shoreline.

There are 411 coastal wetlands covering a total area of almost 49,000 hectares (121,000 acres). Most of these wetlands are concentrated along the rivers emptying into the Lake along Michigan's western shore and in Green Bay (some of the finest examples of Great Lakes marshes are in Green Bay and along the eastern side of the Door Peninsula). However, south of Sturgeon Bay all the way to Chicago, wetland development has been very limited because most of the shoreline consists of high bluffs with narrow, high energy beaches and few unmodified river mouths. At all river mouths urbanization has eliminated the wetlands. Small, remnant wetlands can be found south of Chicago and around the bottom of the Lake. In the Calumet area, some of these are being restored and reconnected to the Lake. From Northern Indiana and continuing into Michigan, massive coastal dunes flank the shoreline for about 370 kilometers (230 miles). These dunes run without interruption, except for river valleys, some cities, and roads, along the entire shore to heights of 100 meters (328 feet) and breadths up to 1.5 kilometers (nearly a mile). They are extensively urbanized with summer homes and permanent residences along many stretches, often very close to the shore. North of Leland, through the Traverse Bays and continuing north to the Straits of Mackinac, the Lake Michigan shore changes again into rocky cliffs and bluffs, cobble beaches, and occasional small embayed wetlands. From the

Straits westerly, the Michigan shore becomes distinct again, with low relief, multiple sand ridges being interrupted by shallow, sheltered bays.

The northern part of the Lake Michigan watershed is climatically cooler, covered with forests, and has a relatively scattered population (except for the Fox River Valley). The southern, more temperate portion of the basin is heavily populated with areas of intense urbanization, industrial development, and productive farmland.

Water quality in the basin varies widely, from nearly pristine in some northern areas to seriously contaminated in others. In the heavily populated and industrial southern tip of the Lake, nearshore water quality is severely diminished. The cause of this poor water quality originates almost entirely from urban sources. Direct stormwater flows as well as discharges from storm sewers into streams and directly in to the Lake contribute sediment, nutrients, pesticides, herbicides, oils, and heavy metals. A recent evaluation of the southeastern basin revealed that of 210 stream miles assessed, 186 were considered unsuitable for aquatic life. Contaminated sediments in rivers and harbors remain a serious problem in the area.

Ten AOCs have been identified on Lake Michigan: Manistique River, Lower Menominee River, Lower Green Bay and Fox River, Sheboygan River, Milwaukee Estuary, Waukegan Harbor, Grand Calumet River/ Indiana Harbor Ship Canal, Kalamazoo River, Muskegon Lake, and White Lake. Contributors of point source pollution are primarily paper mills in the northern basin and steel-related industries in the south. In the past two decades, however, implementation of pollution-control policies has dramatically reduced the amount of pollution being discharged from these sources and, currently, non-point pollution sources are the primary cause of degraded water and air quality in the basin.

Substantial numbers of stocked, breeding-age lake trout are present in the Lake. Spawning and fry production by stocked fish have been recorded at several locations, and wild yearling and older lake trout have also been found in the Lake; however, substantial numbers of adult wild lake trout have not been produced. Pacific salmon abundance has been sharply reduced compared with the peak levels reached between the 1970s and middle 1980s, the cause of which is not completely understood. The biomass (a measure of abundance expressed as weight) of each of the three major forage fish (alewife, rainbow smelt, and slimy sculpin) in Lake Michigan has also changed significantly since the 1970s. Alewife constituted more than 80 percent of the biomass in catches in the 1970s but declined to about 10 percent in the middle 1980s through the 1990s. The biomass of rainbow smelt decreased from between 15 and 20 percent in the 1970s and early 1980s to less than 10 percent in the middle 1980s and 1990s. Slimy sculpin abundance peaked in the late 1970s, but declined in the 1980s and 1990s to less than 20 percent of peak 1970s levels, probably in response to predation by trout, burbot, and introduced salmon.

The predominant development trend in the Lake Michigan basin is continued low-density sprawl. This population shift to the urban periphery and suburbs, together with the demand for low-density development, consumes vast amounts of agricultural lands and open space. Counties in the eastern Lake

Michigan basin, for example, experienced reductions in farmlands acreage of 7 percent to more than 15 percent from 1982 to 1992, pushing the average for that region in excess of the average loss rates for the State of Michigan during that period (7.8 percent). On the western side of the basin, the same trend is apparent. Wisconsin coastal counties on Lake Michigan showed a net gain of 41,584 housing units from 1990 to 1995, nearly half of which were in communities bordering the shoreline.

The largest concentration of steel production in North America is located near the southern tip of Lake Michigan. When fabricating and warehouse facilities are included, the sprawling scale of steel production occupies thousands of nearshore acres and, in some areas, unique dune ecosystems. Steel-making has been a historical polluter of water and soil, and the Lake Michigan steel-making legacy has generated tons of pollutants, some of which are still present in contaminated sediments in nearshore waters and soil within plant boundaries.

The Lake Michigan basin economy supports more than twice as many jobs as the next largest economy among Great Lakes basins (Lake Erie). The basin has the most manufacturing jobs among the individual Great Lakes basins, but employment in this sector has been declining while employment in the service sector has been rising. Between 1970 and 1990, the service sector in Lake Michigan's drainage basin grew nearly 100 percent, and today, over 2 million service sector jobs are located there.

Fish consumption advisories are in effect for lake trout, brown trout, rainbow trout, coho salmon, chinook salmon, whitefish, walleyed pike, perch, smelt, carp, and sturgeon. Large lake trout and brown trout should not be eaten at all, whereas it is recommended that consumption of the others be limited. PCBs are the principal contaminants causing the consumption advisories.

The status of nearshore terrestrial ecosystem health in Lake Michigan reflects the impact of ongoing development pressures on the basin (see Table 8). The health of shoreline species and communities has been rated as *mixed/ deteriorating*, and the effect of shoreline armoring on natural shoreline processes is also *mixed/deteriorating*. Biodiversity in the Lake Michigan basin varies with location, and while representation of biodiversity in lakeshore parks and protected areas is stable, efforts to designate additional biodiversity investment areas have been improving.

7.3 Lake Huron

Renowned for its more than 30,000 islands and its summer cottages, Lake Huron is one of the least developed of the Great Lakes, and is second only to Lake Superior in area. When island shorelines are included, Lake Huron has the longest shoreline of the Great Lakes. It is the third largest freshwater lake in the world in terms of area, and the sixth largest in volume; it boasts the largest island (Manitoulin) of any freshwater lake on Earth. The retention time for water in Lake Huron is 22 years, and the average depth is 59 meters (195 feet).

The U.S.–Canada border divides Lake Huron almost in half. The Canadian portion of the Lake, including Georgian Bay, is wholly in the Province of Ontario. The U.S. portion is located entirely within the State of Michigan. The drainage basin on the Ontario side (86,430 square kilometers or 33,500 square miles) covers twice the area, has approximately five times the shoreline, and roughly 300,000 fewer residents than in Michigan. On both sides of the border, the population density is low (approximately 39 persons per square kilometer, or less than 100 persons per square mile), with Michigan's Saginaw Bay area representing the only large urbanized center on the Lake Huron shore.

The 134,100 square kilometer (51,700 square mile) drainage basin of Lake Huron is predominantly forested (66 percent), with lesser amounts of agricultural land (22 percent), residential and industrial land (10 percent), and other land uses (2 percent). The southern portion of the watershed is developed to a greater degree than the northern portion, although residential and agricultural development dominates in both areas. Pollution is most severe in the waters at, and adjacent to, urban and rural settlement areas. Four AOCs had been identified on Lake Huron (Saginaw River/Bay, Collingwood Harbour, Severn Sound, Spanish Harbour). Collingwood Harbour has had all beneficial uses restored, as a result of the efforts of those involved in the remediation. It has been delisted and is no longer classified as an AOC. Of the remaining three AOCs, Saginaw Bay presents by far the largest problem in terms of remediation.

The wetlands of Lake Huron are generally smaller but more abundant than those in the southern Great Lakes and over half are wetland complexes. Marshes and swamps are equally dominant, and many have significant fen components. They also have more complex vegetative communities than those in the southern Great Lakes. Wetlands along the Canadian shore of Lake Huron are common in the sheltered embayments and creek mouths and in the lees of large islands. Although an accurate estimate of coastal wetlands in this area is not available, 7,159 hectares (17,900 acres) of wetlands have been evaluated for quality on the Canadian side of the Lake.

There are an estimated additional 16,200 hectares (40,500 acres) of coastal wetlands on the Michigan side of the Lake. As a result, Lake Huron's Michigan coast has nearly 37 percent of all coastal wetlands found in the state of Michigan.

Along the Canadian shore of Lake Huron, loss of wetland habitat on a large scale has not occurred because most of the shoreline is sparsely populated. Losses tend to be concentrated around the small urban centers that dot the shore. Within the last 10 years, there has been incremental and site-specific loss of wetland area from agricultural encroachment and cottage development.

Over 40 species of rare plants, 5 significant reptile species, and 59 fish species use the coastal wetlands of Lake Huron. At least half of those fish species are permanent residents in the wetlands, whereas the remainder use them on a temporary basis for feeding, shelter, spawning, nursery, dispersal of young, and migratory wandering.

The fish community in Lake Huron is recovering, but remains unstable after decades of being overharvested and being subjected to the effects of introduced species. Modest numbers of stocked lake trout are reproducing in the Lake, and populations of whitefish are more abundant than at any other time in this century. Walleye and yellow perch are once again abundant. Rainbow smelt and alewife populations are currently stable, but have been reduced in comparison with former peak levels

in the 1970s. In the 1980s, sea lamprey increased in abundance in the northern end of the Lake, imposing high mortality on lake trout and reversing gains that had been made in lake trout restoration in that area.

Where data exist, limited consumption restrictions are in place for lake trout (a coldwater species) down the length of the eastern shore of Lake Huron, from Fitzwilliam Island to north of Grand Bend. PCB is the principal contaminant of concern causing these consumption advisories. The only restriction on eating warmwater/coolwater fish is on smallmouth bass because of mercury contamination.

Of the four indicators used to assess nearshore terrestrial ecosystem health in each Lake, Lake Huron is in the middle when compared with the other four Great Lakes (see Table 8). Loss of shoreline species and communities continues, but there is evidence that improvements have slowed down the rate of shoreline armoring and thus slowed down the rate at which shoreline processes are interrupted. Representation of biodiversity in lakeshore parks and protected areas is rated as *mixed/improving*, but gains in biodiversity investment areas is described as *mixed/deteriorating*.

7.4 Lake Erie

Lake Erie is the fourth largest of the Great Lakes in surface area (25,700 square kilometers, or 9,910 square miles) and the smallest in volume. As the shallowest of the Lakes, the retention time of water in Lake Erie is only 2.6 years. About 90 percent of the Lake's total inflow of water comes from the upper Great Lakes, the St. Clair River, and Lake St. Clair through the Detroit River. The remaining portion comes from precipitation and tributaries. The Niagara River and shipping canals serve as Lake Erie's outlets and drain into Lake Ontario.

Lake Erie, together with the St. Clair River, Lake St. Clair, and the Detroit River, has a watershed of 78,000 square kilometers (30,140 square miles). Most of this watershed is agricultural (59 percent), and the remaining land is forested (17 percent), residential or industrial (15 percent), or under other land uses (9 percent). Several large sand spits project into Lake Erie, creating valuable habitats. These include Long Point, Turkey Point, Rondeau Peninsula, Point Pelee, and Presque Isle. The lake basin can be naturally divided into three sub-basins: the western basin (to the west of Point Pelee), the central basin (between Point Pelee and Long Point), and the eastern basin (to the east of Long Point)—the deepest portion of the Lake.

Of all the Great Lakes, Lake Erie is exposed to the greatest stress from both urbanization and agriculture. The Lake Erie basin has the largest percentage of land use in agriculture of any lake basin, but agriculture is experiencing intense competition from other land uses, especially from urban sprawl and scattered rural development.

The economies of the Lake Erie basin are markedly different in their range and type. They include the Detroit urban-industrial complex, rural agricultural villages, commercial and recreational fisheries, and the water-based cottage and recreational industry. Along the shoreline itself, the economy is generally driven by recreation and tourism, including cottages, marinas, and fishing. Lake Erie is the most biologically productive of the Great Lakes, and its fishing industry is worth approximately Cdn $100 million, of which $40 million is for yellow perch alone.

The total population (Canada and the U.S. combined) within the Lake Erie basin is approximately 13 million, of which nearly 86 percent is on the U.S. side. Over the past decade the population on the U.S. side has been declining, while Ontario's population in Lake Erie's basin has remained stable. The greatest impacts on the Canadian side of Lake Erie have been through growth and expansion of urban areas along streams and rivers, such as the Grand River. Urban development has affected the nearshore by causing erosion, increasing sedimentation, and adding pollutants. Sewage, treated wastewater, and stormwater issues are also high on the list of detrimental environmental impacts within the Lake Erie nearshore. The major causes of these problems are not only the increased residential development but also the conversion of seasonal shoreline cottages to permanent residences that use private septic systems.

Although the Lake Erie basin is the most densely populated and intensively farmed, and the Lake receives large quantities of pollution, it has been mitigated by sedimentation of algae and fine soil particles from soil erosion, both of which tend to adsorb pollutants from the water (then settle at the bottom and become buried). Additionally, Lake Erie's short retention time also accounts for the lower pollution levels (more pollutants flow through to Lake Ontario). Accordingly, the water and fish in Lake Erie have shown low concentrations of toxic contaminants. Seven AOCs have been identified on Lake Erie proper: River Raisin, Maumee River, Black River, Cuyahoga River, Ashtabula River, Presque Isle Bay, and Wheatley Harbour with contaminated sediments having an effect at all seven.

However, because of its shallow depth, relative warmth, and the high fertility of the soils in its basin, Lake Erie is more eutrophic than the other Great Lakes and allows bacteria to thrive during the warm summer months. Beaches all along the shoreline have experienced high bacterial levels leading to closures, but the beaches in the western and central lake basins are particularly affected.

Although investment in municipal and industrial waste treatment, and programs to control agricultural land runoff have achieved excellent results in nutrient management, the near total removal of native vegetation from the basin and the severe exploitation of fisheries followed by exotic species invasions have devastated the original aquatic community of the Lake. While some recovery may be in sight, the long-term impact of exotic species, such as zebra mussels, is unknown. Although mussels have increased water clarity by approximately 75 percent between 1988 and 1991, their feeding habits have led to large changes in the food web, which may result in undesirable changes in fish species populations. They are also suppressing and may be completely destroying populations of native mussels.

The largest concentration of coastal wetlands occurs along the shallow western basin of the Lake, fringing the low-lying shorelines and estuaries in Michigan and Ohio. The U.S. shoreline of the central and eastern basin consists predominantly of bluffs, therefore limiting wetlands to river mouths and to Presque Isle (a 10 kilometer, or 6.3 mile, sand spit). There are 87 wetlands along the U.S. shoreline, encompassing more than 7,937 hectares (19,842 acres). Most of the wetlands have been diked and are hydrologically isolated from the Lake. Fewer but more extensive wetlands are nestled behind the large sand spits along the north shore of Lake Erie in Ontario and at river and creek mouths. Along the Canadian shoreline are 31 wetlands covering 18,866 hectares (47,165 acres). They range in size from 3 to 13,465 hectares (7.5 to 33,663 acres), and over half are wetland complexes consisting mostly of marshes with some swamp and rare fen and bog components.

The coastal wetlands of Lake Erie support the largest diversity of plant and wildlife species in the Great Lakes. The moderate climate of Lake Erie and its more southern latitude allow for many species not found along the northern Great Lakes. Many rare species of plants can be found in Lake Erie's coastal wetlands, and at least 37 significant plant species are found there. The wetlands are also important for fish production because they provide spawning and nursery habitat for many wetland-dependent species, cover for juvenile and forage fish, and feeding areas for predator fish. Forty-six species of fish have been captured in Lake Erie wetlands, and an additional 18 species captured in open water are known to use these wetlands during some part of their lives.

A comparison between the current Lake Erie fish community and the historical community shows that impairment has occurred and is continuing. The status of 34 species of Lake Erie fish are rare, threatened, endangered, extirpated, extinct, or of special concern. Stocked lake trout and coho salmon are not reproducing successfully, and once-abundant levels of forage fish species (such as rainbow smelt, spottail shiners, emerald shiner, gizzard shad, and alewife) have declined. Lake whitefish are continuing to show signs of recovery. Walleye and yellow perch are intensively managed to provide productive recreational and commercial fisheries in the U.S. and Canada.

Lake trout are limited to the eastern basin of Lake Erie because it is deeper and cooler. PCB levels have led to a "limited" consumption advisory for lake trout from Long Point Bay eastward. No consumption restrictions are in effect for any of the warmwater/coolwater indicator fish species of any size in Lake Erie.

Over the past 10 years, 25 navigational areas on or near Lake Erie have been dredged. In 12 of these areas, the dredged material has, at some time, been required to be disposed in a confined disposal facility. Dredged materials from seven AOC sites currently require confined disposal; these sites include the Detroit and Rouge Rivers, River Raisin, and Maumee River in the western basin, and the Ashtabula River, Cuyahoga River, and Black River in the central basin. PCBs are the most commonly identified contaminant that necessitates the confined disposal of dredged material.

The overall health of the nearshore terrestrial ecosystem in Lake Erie's basin has been given one of the lowest ratings of all the Great Lakes (see Table 8). All four indicators used to assess nearshore terrestrial health have been rated as *mixed/deteriorating* or *poor*. Shoreline species and communities have been lost and this trend is continuing; many shoreline processes have been interrupted by armoring.

7.5 Lake Ontario

Lake Ontario ranks as the 12th largest lake in the world, although its surface area of approximately 18,960 square kilometers (7,340 square miles) makes it the smallest of the Great Lakes. Its drainage basin is 64,030 square kilometers (24,720 square miles) and is dominated by forests (49 percent) and agriculture (39 percent). Approximately 7 percent of the basin is urbanized. Water levels of the Lake are controlled by dams and locks in the St. Lawrence Seaway along the St. Lawrence River. Nearly 85 percent of the Lake perimeter is characterized by regular (nearly straight) shorelines sloping rapidly into deep water.

Lake Ontario can be divided into two distinct parts. The main basin reaches a maximum depth of 244 meters (802 feet) and is bounded by the Niagara Peninsula at its west end and the Mexico Bay shoreline in the east. The Kingston basin is much shallower and smaller than the main basin; however, the irregular and highly convoluted shoreline of the Kingston basin accounts for more than 50 percent of Lake Ontario's total shoreline. The shoreline extends for 1,146 kilometers (730 miles), with many embayments and peninsulas in the eastern third of the Lake. The only islands are those near the outlet at the eastern end of the Lake, and Toronto Island.

Wetlands are most abundant in the eastern portions of the Lake. They occur at river mouths, embayments, and behind bars and barrier beaches. In total, 17,607 hectares (44,018 acres) of wetlands have been identified along the shores of Lake Ontario. Dominant plants are often invasive species (introduced or native), such as purple loosestrife, eurasian water-milfoil, reed canary grass, and hybrid cattail. Despite this, 17 rare species of plants have been found in Lake Ontario's coastal wetlands.

Sixty-eight species of fish use coastal wetlands of Lake Ontario, two-thirds of which are permanent residents. The other third use them on a temporary basis for spawning, nursery, or feeding.

The wetlands of Lake Ontario have suffered severe loss over the last two centuries, mainly through agricultural drainage and urban encroachment. Between 1789 and 1979, an estimated 1,518 hectares (3,795 acres) of coastal marsh were lost between Toronto and the Niagara River. That total represented between 73 and 100 percent of the original marsh along these shores. Along the entire U.S. shore, wetland losses have been estimated at nearly 60 percent. Most of the losses are attributable to the heavily populated areas surrounding Oswego and Rochester.

A major source of stress to all coastal wetlands in Lake Ontario is water-level regulation. Water levels have been regulated in the Lake since the construction of the St. Lawrence Seaway in 1959. Prior to regulation, the range of water-level fluctuations during the 20th century was about 2 meters (6.5 feet). Between 1960 and 1976, this range was reduced slightly. Since 1976, however, the range has been reduced to about 0.9 meters (2.9 feet). The lack of alternating flooded and dewatered conditions at the upper and lower edges of the wetlands decreased wetland area, resulting in reduced diversity of plant and wildlife communities.

High sediment loads and excess turbidity have been noted as stressors in several coastal wetlands. Sources are site-specific, but are mostly related to urban and agricultural runoff. Carp are also a serious problem in Lake Ontario marshes and shallow water areas because they resuspend sediments, which increases turbidity, and they destroy aquatic macrophytes. Turbidity problems are compounded by excess nutrients encouraging rapid algal growth which, in turn, decreases water clarity and limits the amount of light reaching rooted plants and the benthic community. Excess nutrients can also cause changes in wetland species, reducing the diversity.

The fish community has improved considerably from a low point in the 1960s. Alewife and rainbow smelt abundance declined in the 1980s in response to increased trout and salmon predation, and to fewer nutrients being added to the Lake. In the 1990s, stocking of trout and salmon was reduced to bring them into better balance with their food supply. Some native fishes are also recovering from the low levels observed in the 1960s. For example, lake whitefish, which typically were most abundant in the eastern end of the Lake, were nearly absent in the 1970s, began increasing in the 1980s, and were 30- to 40-fold more abundant in the 1990s. And in 1995, lake trout, which had been eliminated from the Lake by sea lamprey, habitat loss, and overfishing, began to reproduce naturally after an absence of some 45 years.

Seven AOCs have been identified on Lake Ontario: Eighteenmile Creek, Rochester Embayment, Oswego River, Bay of Quinte, Port Hope Harbour, Metro Toronto and Region, and Hamilton Harbour. Although Buffalo River technically drains into Lake Erie, it is considered an additional Lake Ontario AOC because most of the impacts are in Lake Ontario. Most of these eight AOCs have contaminated sediments and restricitions on fish consumption.

At all locations for which information is available in Lake Ontario and the Niagara River, a “limited” consumption advisory is in effect for lake trout. PCB is the principal contaminant of concern causing the consumption advisories, with levels of mirex and dioxin also of concern in certain locations. There is good long-term information available for both PCB and mirex in rainbow trout at the Ganaraska River, which empties into Lake Ontario. For both contaminants, concentrations declined between 1976 and the mid-to-late 1980s, but have shown no clear trend since then. PCBs declined from 3.9 ppm (parts per million) in 1976 to 0.65 ppm in 1994. Mirex concentration dropped from 0.26 ppm in 1976 to 0.06 ppm in 1994. Mean mercury concentration in walleye in eastern Lake Ontario varied between 0.19 ppm and 0.43 ppm over the period 1981 to 1994, with no clear trend over this period.

The most significant land-use change in the Lake Ontario basin over the past 40 years has been, and continues to be, the urban expansion of the Greater Toronto Area. Low net population growth has been replaced by suburban expansion, extension of the urban fringe, and development of adjacent rural areas.

Lake Ontario’s overall nearshore terrestrial health has been given one of the lowest ratings of the Great Lakes (see Table 8). All four indicators used to assess nearshore terrestrial health have been rated as *mixed/deteriorating* or *poor*. Shoreline species and communities have been lost and this trend is continuing; many shoreline processes have been interrupted by armoring.

8. Connecting Channels

The connecting channels of the Great Lakes consist of the St. Marys River, the St. Clair River, Lake St. Clair, the Detroit River, the Niagara River, and the St. Lawrence River. They are the vital links between the Lakes, carrying the surface-water outflow from one Great Lake to the next and are nearly always considered “nearshore” by the definition set out earlier in this report. The whole of Lake St. Clair is considered nearshore because it is so shallow (mean depth of 4.4 meters, or 14.4 feet). Connecting channels also have an important role in the transport of water, sediments, nutrients, and contaminants.

The nearshore areas of both the Lakes and the connecting channels are affected by the impacts of urbanization, industry, and agriculture; however, connecting channels have the additional impacts of physical alterations for shipping, water-level management, and power generation. Connecting channels are often the most heavily used areas within the basin by humans—such use causing impaired habitat in all the channels, contaminated sediments in most, and many other beneficial use impairments. Therefore, part or all of each connecting channel has been designated as an AOC. RAPs are being developed on each interconnecting channel.

Table 10. Characteristics of the Great Lakes Connecting Channels

Characteristic	River				
	St. Marys River	St. Clair River	Detroit River	Niagara River	St. Lawrence River
Length (km)	121	63	41	58	150
Elevation drop (m)	6.7	1.5	1.0	99.3	1.6
Average Discharge (m^3/s)	2,100	5,097	5,210	5,692	7,739
Watershed (km^2)	2,830	3,368	1,844	3,251	

Source: Edsall, T. and M. Charlton. 1997. *Nearshore Waters of the Great Lakes.* (SOLEC 96 Background Paper)
* International section

A brief description of each of the connecting channels follows, as well as a discussion on problems common to all or many of them.

8.1 St. Marys River

The St. Marys River drains Lake Superior into Lake Huron, dropping 6.7 meters (22 feet) along its length, mostly along the 1.2 kilometer (0.75 mile) long St. Marys Rapids in Sault Ste. Marie. The River itself has several tributaries, but the water entering from these tributaries is only a small fraction of the drainage from Lake Superior. Most of the watershed is forested (95 percent) with the small urban and industrial areas concentrated in Sault Ste. Marie, Ontario, and Sault Ste. Marie, Michigan.

The upper river above the St. Marys Rapids has sandy and rocky shores, the lower river is bordered by extensive marshes in shallow areas of the large lakes, bays, and islands. These wetlands appear in general to be less affected than other connecting channels downstream, but dredging, filling, and sediment contamination have caused site-specific loss of wetland area along the shoreline of the city of Sault Ste. Marie, Ontario.

The entire River has been declared an AOC because of elevated concentrations of contaminants in the water, localized contaminants of the sediments, the presence of fish tumors, localized impairment of the benthos, and localized high bacterial counts. These impacts are especially heavy along the Canadian shore, downstream of Sault Ste. Marie, Ontario, to Little Lake St. George.

8.2 St. Clair River

The St. Clair River drains Lake Huron into Lake St. Clair. It forms an expansive bird-foot delta with many distribution channels, islands, and wetlands where it meets the Lake. The delta is a transitional environment between the River and the Lake. The River above the delta has relatively high flows because the channel is uniform with very few bends or meanders, dropping only 1.4 meters (4.6 feet) between Lake Huron and the beginning of the delta. The natural shoreline has a bank 1.5 to 5 meters (4.9 to 16.4 feet) high, but most of this shoreline is now artificial, especially on the U.S. side. Almost the entire U.S. shoreline and most of the Canadian shoreline consist of residential, recreational, and industrial developments and have been extensively modified. The River also serves as an important port.

Several small tributaries drain into the River; however, the flow in the River comes mainly from Lake Huron. The drainage basin is mostly agricultural (69 percent), with urban areas concentrated in a narrow zone along the River (the larger centers being Sarnia in Ontario and Port Huron in Michigan). Industry is concentrated mainly in the first 14 kilometers (8.75 miles) of the River between Sarnia and Corunna, Ontario.

The lack of shoreline complexity, the fast current, the depth of the River, and wave forces generated by the passage of large commercial vessels limit wetland development along the banks of the River. In fact, indications show that wetlands are now uncommon habitats in the St. Clair River above the delta. The remaining wetlands are therefore particularly important habitats for plants, fish, and wildlife in the River.

Wetland and habitat loss in the River appears to be largely related to extensive bulkheading, shoreline hardening, filling, channelization, and dredging along the shores of the River. Urban encroachment continues to cause wetland loss and impairment on the Canadian side.

The St. Clair River was declared an AOC as a result of the levels of toxic substances in the water, contaminated sediments, impaired benthos, and bacterial contamination. Industry is the main source of pollution, but municipal sewage treatment plants and other point source and non-point source pollutants are also concerns. Although progress has been made in cleaning up the River, impaired benthos still indicate contaminated sediments downstream of industrial outfalls, mainly along the Canadian shoreline.

8.3 Lake St. Clair

Lake St. Clair is a shallow, heart-shaped lake, 1,115 square kilometers (432 square miles) in area, located between the St. Clair River and the Detroit River. The maximum natural depth is only 6.5 meters (21.3 feet), although a commercial shipping channel has been dug across the Lake to a depth of 8.5 meters (28 feet). The Lake has a drainage basin of 12,616 square kilometers (4,890 square miles), which is predominantly agricultural. Tributaries contribute only 2 percent of the flow to the Lake, the remainder being from the St. Clair River.

Lake St. Clair and the St. Clair Delta contain some of the largest coastal wetlands in the Great Lakes. Estimates of the extent of these wetlands vary. The topography surrounding much of the Lake, especially in the Delta, is almost flat; therefore water-level fluctuations greatly affect the extent and position of these wetlands. Large changes in wetland area are especially great between years of high and low water levels. These changes are important for the diversity of habitat.

On the Canadian side of the St. Clair Delta, there are at least 12,769 hectares (31,923 acres) of coastal wetlands, a third of which have been diked for intensive waterfowl management. On the U.S. side of the delta, there are around 3,500 hectares (8,750 acres) of wetlands. Outside the delta, very few wetlands occur along the highly developed southern and western shores. Overall, these wetlands have been reduced by 41 percent between 1868 and 1973.

Although most of the U.S. shoreline is now developed with marinas, urban and cottage developments, wetland loss from urban and recreational encroachment continues to be a problem. Along the Ontario shoreline, much of the loss results from large-scale conversion of wetlands to agriculture. More recently, loss has been caused by agricultural drainage, but some loss has also resulted from marina and cottage development. Shoreline development, dredging and placement of dredge spoils have also taken their toll on habitat.

Clinton River on the western side of the Lake has been designated an AOC as a result of sediment contamination, fish edibility restrictions, the incidence of tumors in fish, degraded benthos, elevated phosphorus levels and bacterial counts, and habitat loss. Most of these are localized problems. Sources of pollution include industrial and municipal point sources, urban and rural non-point sources, combined sewer overflows, and contaminated sediments.

8.4 Detroit River

The Detroit River connects Lake St. Clair to Lake Erie. Around 95 percent of the total flow in the River enters from Lake St. Clair, and the remainder flows from tributaries. The Canadian portion of this watershed is largely agricultural (90 percent), the remaining area consisting of urban, residential and industrial lands located around Windsor in the northern reaches of the River. The U.S. portion of the watershed is only 30 percent agricultural, and the remainder is residential (30 percent), urban (30 percent), and industrial (10 percent). Over 5 million people live in the Detroit River watershed.

Eighty-seven percent of the U.S. shoreline and 20 percent of the Canadian shoreline have now been modified with revetments and other shoreline hardening structures. Consequently, many of the historical coastal wetlands have been lost through dredging, bulkheading, and/or backfilling. The remaining wetlands mostly occur on islands in the River. In recent years, loss of wetlands along the shores has diminished, but incremental loss from agricultural conversion, shoreline modification, marina development, and urban encroachment is still a concern. Additionally, the shipping channel is dredged each year for navigation, substantially changing the River morphology.

The heavy traffic at the port (Detroit is the busiest port in the Great Lakes), the large urban areas, and the numerous industries contribute to the pollution of the River and its wetlands. The Detroit River and the Rouge River have both been identified as AOCs. Sediments in many stretches of the River are contaminated with heavy metals, oils, and PCBs, especially along the U.S. side of the River.

8.5 Niagara River

The Niagara River drains Lake Erie into Lake Ontario. The River drops close to 100 meters (328 feet) along its course, most of which is at Niagara Falls. The natural shoreline of the River consists of low banks in the upper portion of the River and a deep gorge cut through sedimentary deposits in the lower River below Niagara Falls.

Several tributaries flow into the River from the U.S. and Canada, but they contribute only a small fraction of flow to the River. On the Canadian side, land uses within the watershed are dominated by agriculture (32 percent), abandoned agricultural land (23 percent), urban land (23 percent), and forests (16 percent). On the U.S. side, farmland and forests are found in the upper parts of the watershed, but the lower parts are predominantly urban. Large urban centers along the River include Fort Erie and Niagara Falls in Ontario, and Buffalo and Niagara Falls in New York.

The fast flow of the River has precluded the development of wetlands in many reaches of the River. Although no specific studies have been done on wetland loss in the Niagara River, many wetlands are known to have been reduced in size or lost. Loss of, and stress to, wetlands from shoreline modification and urban encroachment continue to be concerns.

The Niagara River has been declared an AOC as a result of excessive toxic chemicals in the water, sediment contamination, fish edibility restrictions, the incidence of tumors in fish, degraded benthos, and elevated phosphorus levels. Sources of pollution include industry outfalls, sewage treatment plants, other point sources, and non-point sources. Wetlands near these sources are vulnerable to eutrophication and contamination from toxic chemicals.

8.6 St. Lawrence River

The St. Lawrence River is the outlet of the Great Lakes system, draining Lake Ontario and extending 870 kilometers (540 miles) from the Lake to the Gulf of St. Lawrence. This report looks at the 186 kilometer (116 mile) section of the River from Wolfe Island at the outlet of Lake Ontario to the Quebec border (this includes the international section of the River and the Ontario shore of Lake St. Francis).

Water level and flows have been regulated in this section of the St. Lawrence River since the construction of the St. Lawrence Seaway in 1959. Prior to this, the River resembled the large riverine estuary in the Thousand Island section. The middle and lower sections down to Cornwall were part of the riverine system with many islands and shoals, and many rapids in the lower reaches of the international section. The creation of Lake St. Lawrence and the dredging for navigation and power production greatly changed the character of the River and altered these habitats.

The section of the St. Lawrence River downstream of Cornwall, Ontario, and Massena, New York, has been declared an AOC as a result of high levels of toxic substances in the water, contaminated sediments, fish consumption advisories, tumors in fish near Cornwall, degraded benthos, elevated counts of fecal coliform bacteria, and eutrophication from elevated phosphorus downstream of Cornwall. Bioaccumulation of PCBs has been observed to be very high in red-winged blackbirds and tree swallows from coastal wetlands on the Akwesasne reserve near Cornwall and Massena.

8.7 Common Stressors of the Connecting Channels

There are many examples of human-induced stressors that have an impact on the ecosystems of the connecting channels, including erosion from the passage of ships, dredging and channelization, shoreline modification, hydroelectric power plants, excess nutrients, contamination of water and sediments with toxic chemicals, agricultural and urban encroachment, and invasive non-indigenous species.

The effect of the passage of large commercial vessels on Great Lakes nearshore water habitat and biota has not been extensively studied, but the areas of greatest concern are sections where the vessels follow a dredged channel that occupies a large portion of the cross-sectional area of the connecting channel. In these areas, the larger vessels fill much of the channel and as they pass, they sharply disrupt the normal water level and flow conditions. This water movement is believed to uproot or fragment submerged aquatic plants and to erode the sediments to which these plants are attached. A study of the St. Clair and Detroit Rivers revealed that the density and diversity of submerged aquatic plants were lower in the channels used by large commercial vessels than in the adjacent channels not used by such vessels. These effects are even greater during the period of solid ice cover and can substantially increase the amount of living plants, decaying plants, and benthic invertebrates that are swept from the shallow nearshore portions of the river bed into the main channel and then moved rapidly downstream as "drift." The accelerated transport of this material in winter, when natural production of aquatic plants and animals is low, represents a considerable loss of material and energy that would otherwise be recycled in summer to provide sustenance to plants and animals in these portions of the ecosystem. Commercial and recreational vessels also cause excess wave action, which leads to more erosion and more turbidity in coastal wetlands and other nearshore habitats.

Vessel passage in winter also destroys ice bridges used by mammals, including wolves and moose, to cross the St. Marys River; and it closes natural open pools in the ice field where bald eagles capture fish in winter. The effects of vessel passage in winter on the incubation and survival of lake herring eggs spawned in the St. Marys River just before ice cover forms in early winter may be less than previously thought.

Lake St. Clair, portions of the connecting channels, and certain other sheltered portions of the Great Lakes nearshore waters are important resting and feeding areas for migrating waterfowl. However, recreational boaters can flush and otherwise disturb flocks of resting and feeding birds, causing them to unnecessarily expend energy needed for migration, survival, and reproduction. They can also force them to seek less favorable feeding and resting habitat or to alter their migratory schedules. To help relieve this stress, recreational boating is restricted seasonally in substantial portions of Lake St. Clair, which have been declared refuges for migrating waterfowl.

Urban, recreational, and agricultural encroachment not only causes habitat and wetland loss, but also stresses remaining habitat. In many cases, shoreline hardening (such as bulkheading and diking) is the solution to erosion. Where this hardening is adjacent to remaining wetlands, it restricts their connection to upland habitats and limits the landward migration of wetlands during high-water periods. This causes a backstopping effect, reducing the size and diversity of wetland communities. About half the wetlands in Lake St. Clair and the St. Clair Delta have been diked. Recreational and urban developments also fragment the remaining habitats.

Cottage development produces site-specific stresses on habitats. These stresses result from dredging and channelization for boat slips and marinas and hardening of the shoreline.

Water levels and flows in the Great Lakes and connecting channels are of considerable importance for hydroelectric power generation, for commercial navigation, for recreational boating, and to owners of residential or commercial property in low-lying coastal areas. Water extraction and water-level regulation are additional stresses to nearshore habitats and wetlands. Water levels in Lakes Superior and Ontario and outflows from those Lakes are regulated by dams in the St. Marys and St. Lawrence Rivers, respectively. Recent proposals have been rejected to further regulate the levels and flows in the system for the benefit of navigation and hydropower interests, and to reduce flooding and shoreline erosion in commercial and residential areas during high-water years. The decision not to regulate the system further expressly recognized the ecological importance of retaining the natural fluctuations in levels and flows in the system.

The most adverse direct ecological effect of level and flow regulation is felt in coastal wetlands. These wetlands are adapted to short-term flooding and draining by storm tides (seiches) and to seasonal and longer-term changes (i.e., changes that occur over years or decades) in lake level, limiting the invasion of woody vegetation and rejuvenating the wetland vegetation.

The effect on the fish community of habitat changes caused by the dams is difficult to assess because of a lack of pre- and post-impoundment data. Clearly, however, northern pike, sunfish, bass, and brown bullhead still spawn successfully and thrive in the St. Lawrence River above the dams, while muskellunge may have declined.

Lake sturgeon have declined, probably through loss of spawning habitat, blockage of migration routes, or both. The historical range of lake sturgeon in New York state waters of the Great Lakes basin is poorly understood because exploitation and population decline occurred before 1950. By that time few lake sturgeon remained in the St. Lawrence River's Thousand Islands region; the only self-sustaining population occurred below the Moses-Saunders Dam. No fish passage facilities exist at the Iroquois Dam, which remains open most of the year; the eel ladder on the Moses-Saunders Dam is not designed to pass lake sturgeon. The older dams on all the major tributaries to the international section of the St. Lawrence River may have contributed to the early decline of the area's lake sturgeon. Efforts are under way to re-establish lake sturgeon in the U.S. tributaries to the St. Lawrence River and to assess the potential for restoring the population in the St. Lawrence River above and below the Moses-Saunders Dam.

Walleye were historically common in the St. Lawrence River, but their numbers declined sharply after the construction of the St. Lawrence Seaway and Power Project in 1958, probably as a result of the inundation of the rapids and rocky whitewater areas that were their preferred spawning habitat. The population is showing signs of recovery and abundance has increased irregularly from 1983 to 1993.

The construction (and accompanying dredging and filling) and operation of dams alter, and continue to act as stressors on, the local ecosystems. For example, in Lake St. Francis on the St. Lawrence River, modifications to the hydrological regime have resulted in an increase of 36 centimeters (14 inches) in the mean water level, and annual water-level fluctuations no longer occur.

Hydroelectric power generation plants are located on some of the connecting channels (in the U.S. and Canadian waters of the St. Marys River, on the Niagara River, and on the Moses-Saunders Dam on the St. Lawrence River). The effects of these particular plants on the fish community have not been fully assessed; however, some loss of fish through collision with turbine blades and other internal surfaces is inevitable (as discussed in section 6.1). The extent of the rapids in the St. Marys River has been substantially reduced because most of the flow is diverted for power production. Historically, the rapids supported a productive fishery for lake whitefish; the remaining rapids now support a valuable recreational fishery for stocked trout and salmon. More than half the flow of the Niagara River is diverted for power production, causing dewatering of some marsh areas.

Despite the stresses on the connecting channels, a wide range of plant, fish, and wildlife species depends on the nearshore habitat and wetlands found there. Significant and rare species of plants can be found in the wetlands. For example, in Canada the rare sedge *(Carex suberecta*) is found only in the coastal wetlands of the Detroit River. Many species of fish use these habitats either permanently or temporarily for spawning, nursery, shelter, or feeding. Lake St. Clair is one of only two sites in the Great Lakes with large muskellunge populations. The only large spawning area for muskellunge left in Lake St. Clair is in Anchor Bay, Michigan. And the shallow marshes of the delta are the only known nursery areas for muskellunge in the entire St. Clair River, Lake St. Clair, and Detroit River system. The St. Marys River, downstream from the dam at Sault Ste. Marie, and the Niagara River provide spawning habitat for Pacific salmon and rainbow trout, which also spawn in many of the tributaries of the Great Lakes. Several species of reptiles and amphibians also depend on these habitats. The only reported site in Ontario for the northern dusky salamander is in the Niagara River wetlands.

Many wetlands in the connecting channels have been identified as significant areas of waterfowl production, particularly the St. Clair Delta, which has been identified as one of the most significant areas for waterfowl production, staging, and migration in the Great Lakes. Approximately 16 percent of all the Great Lakes coastal wetlands of importance to waterfowl are found in the St. Clair Delta. The wetlands are important migratory staging areas and are used as habitat or breeding areas by other birds (non-waterfowl). Walpole Island marshes also support the largest number of nesting pairs of Forster's tern on the Great Lakes and provide nesting habitat for the black tern. Even areas that are not important breeding sites or migration corridors can be useful to waterfowl when nearby wetlands with less current, shipping, or thermal pollution are frozen. Examples of these areas include the wetlands of the Niagara River, Detroit River, and St. Clair River.

9. Management Challenges

The fundamental challenge for managers and decision makers is to understand the nearshore as an ecosystem and to obtain enough relevant information to make informed decisions. Obtaining and communicating such information is a formidable challenge for researchers and those responsible for monitoring the state of the ecosystem.

The SOLEC three-level framework of health, stressors, and sources (see Figure 3) offers a way both to organize thinking about the system and to develop indicators that can be used at all three levels to define desired states and measure progress.

Although the ecosystem is complex, an urgent need exists to agree upon the present state, desired states, and key steps needed to attain what is desired. Without agreement on these issues, rational decision-making or measuring of progress will be difficult.

The development of community-based Remedial Action Plans (RAPs) for Areas of Concern, Lakewide Management Plans (LaMPs), Fisheries Management Plans, and various species recovery plans provides an opportunity to involve the necessary interest groups and to develop practical plans; but these planning mechanisms have yet to reach full potential.

Specific challenges need to be met in the next two years in the context of the following priority issues: managing information, integrating programs, integrating management efforts, using land efficiently, identifying priority areas to preserve and protect, and reaching consensus on indicators.

Information management

The challenge is to bring together available information on the state of the nearshore ecosystem into accessible GIS (Geographic Information System) based formats and systems. This is especially the case for living resources such as plant and other biological communities; various kinds of coastal wetlands, including information on quality and which areas are threatened with loss; and fisheries, including fish stocks and critical habitat.

Integration of programs
The challenge is to integrate the concepts of biodiversity and habitat into existing programs that, traditionally, are devoted to pollution control or natural resource management for harvest.

Integrative management
The challenge is to integrate LaMPs, RAPs, fisheries management plans, and other planning activities so that they become fully viable management mechanisms, useful for decision makers throughout the Great Lakes basin ecosystem in taking action and assessing results.

One of the reasons why consensus on Great Lakes ecosystem health indicators remains elusive is that a series of conflicting objectives and competing agendas have arisen between the many administrative jurisdictions in the Great Lakes basin. There are conflicting opinions about long-term goals for the Great Lakes. For example, should self-sustaining food webs be maintained, or should the put-and-take sport fishery be optimized?; and what are the most useful ecosystem features to monitor? Various jurisdictions have competing mandates, competing time scales, and competing space scales. The resulting management challenge involves identifying ways to improve communication and cooperation between and within these different jurisdictions, as well as integrating management efforts. The challenge of resolving multiple and sometimes conflicting goals lies within the general goal of integrative management.

Efficient land use
The challenge is to find ways to promote land use that is both efficient and protective of high-value habitat.

As discussed during SOLEC 96, changing land use is one of the greatest sources of ecosystem disruption and loss. Human population growth in the Great Lakes basin is expected to continue. The challenge is to find ways of accommodating this growth and use the land in ways that sustain both economic and ecological health. A major step in accomplishing this is to find examples of success and share the information.

Priority areas
The challenge is to identify areas of unusual importance to the health and integrity of the Great Lakes ecosystem for priority attention.

The authors of the SOLEC 96 paper “Land by the Lakes” succeeded in using available information to identify priority land areas that have exceptional ecological importance. Twenty “biodiversity investment areas” were identified (Figure 17). These places present key opportunities to create large areas that, if protected, could preserve ecological integrity and help protect the health of the Great Lakes ecosystem. The challenge is to build upon this initial work, refining identification of key land areas and also identifying key areas in coastal wetlands and the aquatic nearshore. Information to support identification of similar priority areas for coastal wetlands and aquatic areas will be developed as background material for SOLEC 98.

Given the findings that existing protection and restoration programs are inadequate to meet the continuing stresses to habitat and physical processes, a conservation strategy for Great Lakes coastal areas is urgently needed. This strategy should seek to involve all levels of governments and other stakeholders, reflect commitments to biodiversity conservation and sustainable development, and secure broad support from Great Lakes citizens. It should place special emphasis on protecting large core areas of shoreline habitat within 20

Biodiversity Investment Areas. The Biodiversity Investment Areas are clusters of shoreline areas with exceptional biodiversity values that present key opportunities to create large protected areas that will preserve ecological integrity and, ultimately, help protect the health of the Great Lakes themselves.

Indicators

The challenge is to develop easily understood indicators to support an understanding of the state of the system and to obtain widespread agreement on what needs to be done to measure progress.

At present, there is no agreed-upon system or set of Great Lakes ecosystem indicators that are monitored and reported on to measure progress toward achieving the purpose of the Great Lakes Water Quality Agreement. Working to reach that consensus is an important challenge facing ecosystem management efforts in the Great Lakes basin.

Indicators that everybody agrees on are useful because they help define the type and amount of information that needs to be gathered. The U.S. and Canada have spent billions of dollars and uncountable hours of work attempting to reverse the effects of toxic chemical pollution, overfishing, and habitat destruction. In order to justify the tax dollars devoted to Great Lakes environmental issues, environmental management agencies must be able to demonstrate the accomplishments of past programs and, furthermore, to ensure that the success of future or continuing programs will be commensurate with the resources expended. The focus of SOLEC 98 will be on developing Great Lakes indicators to help determine the state of the ecosystem health and on laying the foundation for future reporting.

Figure 17. Shoreline Biodiversity Investment Areas

Source: Reid, R. and K. Holland. 1997. *The Land by the Lakes: Nearshore Terrestrial Ecosystems.* (SOLEC 96 Background Paper)

10. Glossary of Terms

adsorb - Adhere to solid particles.

alvars - Naturally open areas of thin soil over limestone or marble bedrock, which host a distinctive vegetation community, including a considerable number of rare plants.

anadromous - Fish that spend most of their life in open waters, but then migrate to tributaries to spawn, e.g., Atlantic salmon.

Area of Concern (AOC) - An area within the Great Lakes basin recognized by the International Joint Commission where 1 or more of 14 beneficial uses are impaired or where the objectives of the GLWQA or local environmental standards are not being achieved.

armoring (shoreline hardening) - The installation of artificial shoreline structures designed to prevent erosion and protect properties from being washed away.

beneficial uses - The 14 uses that, if impaired in an Area of Concern, the Parties to the GLWQA will strive to restore through the Remedial Action Plan process.

benthic - Occurring at the bottom of a body of water.

bioaccumulation - The accumulation and concentration of certain persistent chemicals from water or sediment to organisms in a food chain.

biodeposited - Deposited as part of the remains of a dead organism.

biological diversity - The spectrum of life forms and the ecological processes that support and sustain them. Biological diversity is a complex of four interacting levels: genetic, species, community, and landscape. "Biodiversity" is the shortened form.

biomagnification - A cumulative increase in the concentration of a persistent substance in successively higher trophic levels of the food chain (e.g., from algae to zooplankton to fish to birds).

body burden - The concentration of contaminants carried in the body.

bogs - Wetlands with no significant inflows or outflows, receiving water primarily from the atmosphere.

bulkheading - The placing of a low wall of stones, concrete, or piling to protect a shore from wave erosion; does not extend out into a lake.

confined disposal facility - A facility providing a contained disposal area for contaminated sediments removed during dredging operations.

cryptosporidiosis - An illness due to infection with the protozoan *Cryptosporidium*, which causes diarrhea, stomach cramps, upset stomach, and fever.

DDT (dichlorodiphenyltrichloroethane) - A highly toxic, chlorinated hydrocarbon insecticide. DDT is now banned from use, but residual amounts remain in the aquatic environment from the long history of its use and environmental persistence.

dieldrin - A highly toxic persistent insecticide.

dune and swale - Dunes (or ridges) that run parallel to a lake and on the ancestral lake bed. The dunes are dry and sandy; the swales are wetland areas.

ecoregion - Large landscape area defined by climate, physical characteristics, and the plants and animals that are able to live there.

ecosystem - A biotic community and its abiotic environment, considered together as a unit. Ecosystems are characterized by a flow of energy that leads to trophic structure and material cycling.

eutrophication - The process of fertilization that causes high productivity and biomass in an aquatic ecosystem. Eutrophication can be a natural process or it can be a cultural process accelerated by an increase of nutrient loading to a lake by human activity.

evapotranspiration - Evaporation of water from soil, and transpiration of water from plants.

exotic species - Non-native plant and animal species.

extirpated - A plant or animal that has been eliminated from a region.

fens - Wetlands that form where alkaline groundwater seeps to the surface.

food chain - A specific nutrient and energy pathway in ecosystems, proceeding from producer to consumer.

forage fish - Fish that eat plankton as a mainstay of their diet and are consumed by other fish higher in the food chain.

fry - A recently hatched fish.

global climate change - Alteration of temperature and precipitation patterns throughout the world caused by human activity.

habitat - The place where an organism lives, including its biotic and abiotic components. Habitat includes everything an organism needs to survive.

hormone disruption - Certain chemicals may mimic or interfere with hormonal actions; possible effects include behavioral changes, reproductive abnormalities, altered immune response, hormonal imbalance, infertility, and tumors in reproductive tissue.

indicator - A measurable feature that singly or in combination provides manageable and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality.

indigenous - Native to a region.

longshore current - A nearshore current that flows parallel to the shore.

macrophytes - Large plants easily visible without a microscope.

malignancies - Cancerous tumors.

marshes - Wetlands dominated by non-woody vegetation that emerges above the soil or water.

neoplasms - Tumorous growths.

non-point source pollution - Source of pollution in which wastes are not released at one specific, identifiable point but from a number of points that are spread out and difficult to identify and control, such as surface runoff from precipitation or atmospheric deposition.

PAH (polynuclear aromatic hydrocarbons) - A class of organic compounds formed through incomplete combustion and that have cancer-producing properties.

Parties - The Governments of Canada and the United States.

PCBs (polychlorinated biphenyls) - A class of toxic organic compounds used in many industrial applications. PCBs contain one or more atoms of chlorine, are resistant to high temperatures, and do not break down in the environment. They are also widely distributed in the environment and food chains.

piscivorous - Fish-eating.

point source pollution - Easily discernable source of pollution such as a factory pipe.

primary consumers - The level of the food chain that first consumes food photosynthesized by plants.

raptor - A bird of prey.

Remedial Action Plans (RAPs) - Plans that embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern.

revetments - Facings of stone, concrete, or other material to protect the banks of a lake or river from erosion; usually built at some angle, unlike a bulkhead which is vertical.

runoff - All water flowing through streams and rivers that goes into the lakes.

species - A group of individuals that can interbreed successfully with one another, but not with members of other groups. Plants and animals are identified as belonging to a given species on the basis of similar characteristics.

stakeholders - Everyone with an interest or a stake in something.

surface runoff - Water flowing in streams and over the ground's surface during a rainstorm or snowmelt.

sustainability - Long-term management of ecosystems to meet the needs of present human populations without interruption, weakening, or loss of the resource base for future generations.

swamp - Wetlands dominated by trees or shrubs.

toxin - A chemical, physical, or biological agent that causes disease or some alteration of the normal structure and function of an organism. Onset of effects may be immediate or delayed, and impairments may be slight or severe.

watershed - Land area that delivers runoff water, sediment, and dissolved substances to a major lake or river and its tributaries.

wetland - An area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and whose soils are indicative of wet conditions.

wetland complex - A group of wetlands that are biologically connected because of close proximity, creating a mosaic of habitat for wetland species.

11. List of Figures and Tables

12. Photo Credits

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http://www.epa.gov/glnpo/

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13. SOLEC 96 Background Paper Information

The SOLEC 96 background papers consist of:
Nearshore Waters of the Great Lakes (ISBN 0-662-26031-7),
Coastal Wetlands of the Great Lakes (ISBN 0-662-26032-5),
Land by the Lakes: Nearshore Terrestrial Ecosystems (ISBN 0-662-26033-3),
Impacts of Changing Land Use (ISBN 0-662-26034-1), and
Information and Information Management (ISBN 0-662-26035-X).

The SOLEC 96 background papers may be accessed via the Internet from the SOLEC home page:
http://www.cciw.ca/solec/

Hardcopies may be obtained from the addresses listed at the bottom of page ii.