Great Lakes Restoration & the Threat of Global Warming

A Report by the Healing Our Waters® - Great Lakes Coalition

May 2008

HEALTHY LAKES HEALTHY LIVES™

HEALTHYLAKES.ORG

Great Lakes Restoration & the Threat of Global Warming

May 2008

Prepared for the Healing Our Waters®-Great Lakes Coalition
by Dave Dempsey (Great Lakes Policy Advisor, Clean Water Action), Jane Elder (President, Jane Elder Strategies), and Donald Scavia (Professor of Natural Resources and Environment, University of Michigan).

ACKNOWLEDGMENTS

This report was made possible through the generous support of the Peter Wege Foundation and the Joyce Foundation.

The authors thank the Union of Concerned Scientists and the Ecological Society of America for their contributions to understanding the impacts of global warming in the Great Lakes area, as outlined in their 2003 report, "Confronting Climate Change in the Great Lakes Region: Impacts on Our Communities and Ecosystems," and in the 2005 update to the report's executive summary, compiled by Dr. George Kling and Dr. Donald Wuebbles.

We also appreciate the resources provided by the National Park Service, the Presidential Climate Action Project, the Brookings Institution and multiple other sources, cited in the text, whose perspectives have contributed to this report.

We are also grateful for review comments and assistance provided by Andy Buchsbaum (Regional Executive Director, National Wildlife Federation), Roger DiSilvestro (Senior Editor, National Wildlife Federation), Nora Ferrell (Valerie Denney Communications, Zoe Lipman (Regional Senior Manager, National Wildlife Federation), Chad Lord (Policy Director, National Parks Conservation Association), Jordan Lubetkin (Senior Regional Communications Manager, National Wildlife Federation), Tracey McIntire (Media Relations Manager, National Parks Conservation Association), Michael Murray (Staff Scientist, National Wildlife Federation), Jeff Skelding (Director, Healing Our Waters—Great Lakes Coalition), and Amanda Staudt (Climate Scientist, National Wildlife Federation).

Report design and layout by Sara E. Jackson (National Wildlife Federation).

Cover Photo: Boy on the shores of Lake Michigan at Van Buren State Park in South Haven, MI. Healing Our Waters Coalition/Connie Tameling.

HEALTHY LAKES HEALTHY LIVES™

HEALTHYLAKES.ORG

Table of Contents

PHOTO: Healing Our Waters Coalition/Pamela Miller

Three friends jump off an old dock in Rockport Harbor, MI., and into Lake Huron, which is a destination for friends and families looking to have a good time. The lake is also likely to see water levels drop by almost 3 feet unless lawmakers act to curb global warming.

PHOTO: Healing Our Waters Coalition/Karen Bunker

Introduction

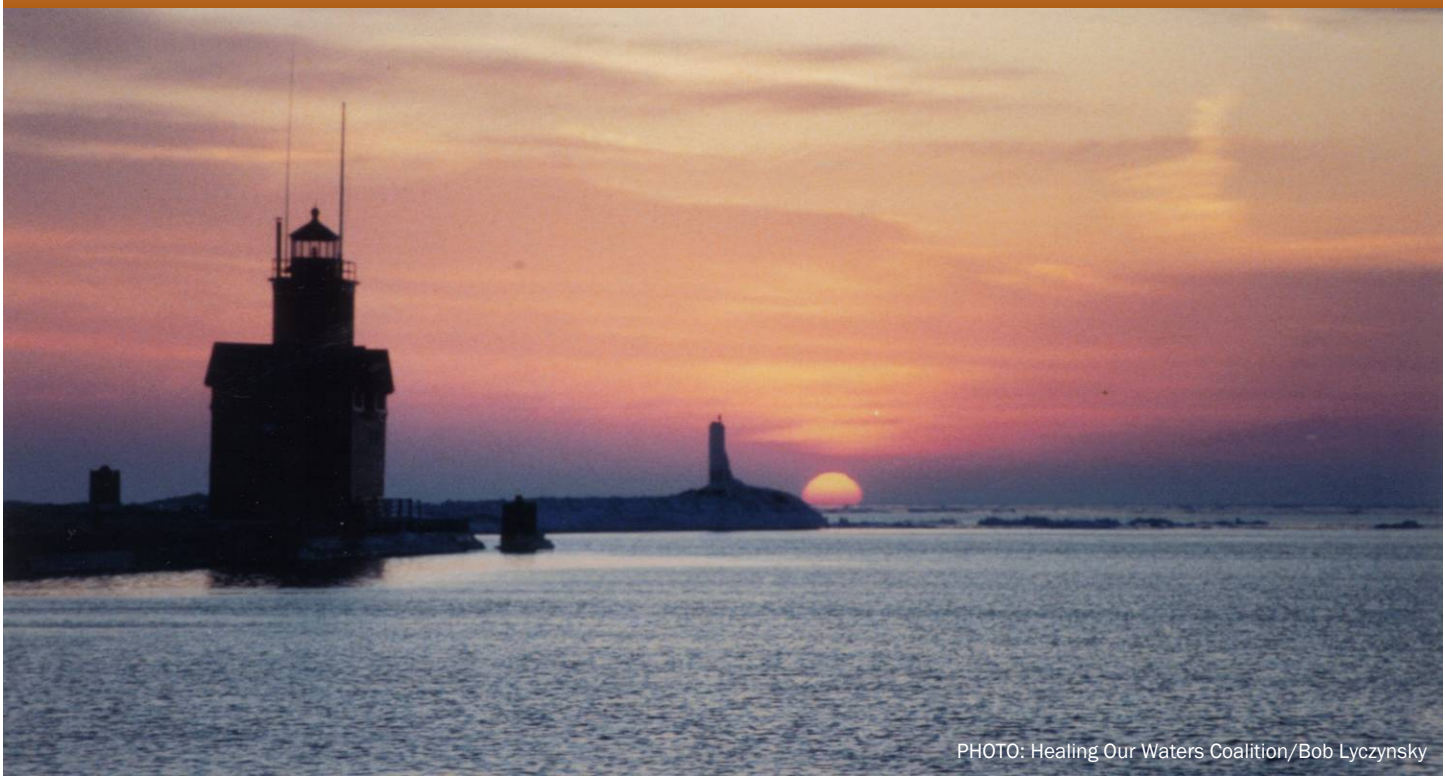


PHOTO: Healing Our Waters Coalition/Bob Lyczynsky

The Earth's climate is warming, and the impacts are already being observed in the Great Lakes—the source of nearly a fifth of the world's surface freshwater. This report synthesizes current climate change science and presents the likely impacts warming temperatures will have on the Great Lakes, people and wildlife. It also provides recommendations for curbing global warming while at the same time preserving the resilience and adaptive capacity of the Great Lakes ecosystem.

The lakes likely will experience a wide range of negative impacts as air and water temperatures increase.

- Daily high temperatures in the region will increase 5.4 to 10.8 degrees relative to what was typical from 1961-1990, with wintertime temperatures increasing even more than summer temperatures.
- Increased evaporation from warming lakes—particularly in winter—is expected to result in less ice cover, contributing to lower water levels and increases in lake-effect snow. Lake levels could drop during the next century by approximately 1 foot on Lake Superior, 3 feet on Lakes Michigan and Huron, 2.7 feet on Lake Erie, and 1.7 feet on Lake Ontario.
- Water quality will likely worsen as more intense storm events will send polluted urban and agricultural runoff to our waterways, leading to drinking water impacts, beach closings and higher costs to water suppliers.
- Biological dead zones will increase, jeopardizing fish and other aquatic life.
- Great Lakes forests and grasslands will change as plants adapted to the area confront increasingly unsuitable habitat. The ranges of some plants and animals will shift northward, while other creatures will vanish.

The Great Lakes are already a highly stressed ecosystem, and climate change will exacerbate existing threats to the lakes. Specifically, global warming will:

- Make the Great Lakes more suitable for some non-native aquatic invasive species that out-compete native species for food and habitat.

- Shrink or dry up coastal wetlands that filter pollution and provide a home for fish and wildlife.
- Expose toxic sediments to people and wildlife posing public health risks.
- Increase sewage overflows resulting from increased storms resulting in beach closings.
- Increase pressure to supply Great Lakes water to areas outside the region will increase as water resources decline and become more scarce.

People, businesses and communities will see changes to the regional economy and quality of life, including potential conflicts between shoreline property owners and the public; diminished fishing, hunting and swimming opportunities; challenges to our economy such as impacts to the shipping industry.

The good news is that there are solutions.

Reducing greenhouse gas and other emissions will curb global warming pollution and limit the magnitude of changes to the climate and to natural ecosystems. It is imperative that the federal government move swiftly to reduce emissions 80 percent by the middle of the century—a level of reduction that climate scientists have deemed necessary to avoid the worst impacts of global warming.

The impacts of warming can also be reduced if government and society follow advice from leading scientists who have outlined measures for preserving ecological resilience by maximizing options for species protection and biodiversity maintenance. These measures will restore vital ecosystem services such as water filtration and storage, pollination, soil enrichment and support of the food web in and around the Great Lakes.

Many of these measures have been incorporated into a comprehensive strategy to restore and protect the Great Lakes. Inserted into federal legislation, the strategy is the subject of a national campaign by the Healing Our Waters-Great Lakes Coalition. The campaign and other stakeholders (including those from affected communities) are working to secure the resources to:

- modernize sewage treatment plants and clean up sources of sewage overflows;
- remove and treat contaminated sediments in Great Lakes harbors and bays;
- protect habitat, fish and wildlife;
- prevent new invasive species from reaching the lakes;
- expand research and monitoring capacity in federal agencies such as the Environmental Protection Agency, U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration and at America's world-class universities; and
- strengthen the capacity of federal agencies to support restoration.

Each of these objectives not only restores and protects the Great Lakes from historical stresses but also is vital to limiting the damages that global warming will bring. In addition, the region is moving to adopt the Great Lakes Water Resources Compact, a tool for combating global warming impacts by addressing the threats of water diversions and unwise water use.

Restoration strategies that increase the lakes' ability to withstand stress can complement and support aggressive efforts to reduce greenhouse gas emissions. Nevertheless, some warming will take place over coming decades because past emissions will linger in the atmosphere and because some time will elapse before communities can adopt new energy sources.

Delay in confronting global warming and the protection of the Great Lakes will only make the problems worse and the solutions more costly. It is imperative that lawmakers act now to stand up for the Great Lakes—a national resource that millions of people depend on for their drinking water, jobs, and way of life.

The Great Lakes Restoration Plan

Restoring the Great Lakes will lead to cleaner, healthier beaches. North Avenue Beach in Chicago offers the opportunity for fun and refreshing summer recreation.

PHOTO: AP Photo/Brian Kersey

The Great Lakes are subject to a variety of environmental, economic, social and ecological threats, as this report discusses in later pages. To deal with these challenges, interested parties in the Great Lakes region, including federal, state, local and tribal government officials and private sector stakeholders, united at the end of 2004 to form the Great Lakes Regional Collaboration (GLRC), a group that would devise a comprehensive strategy for restoring the Great Lakes and ensuring their long-term viability in the face of continued, but sustainable, development. This endeavor ultimately engaged the skills of more than 1,500 individuals and eight strategy teams focused on different goals. The teams solicited public input, developed recommendations and worked together to produce a plan, the "Great Lakes Regional Collaboration Strategy to Restore and Protect the Great Lakes"—also known more colloquially as the Great Lakes restoration plan—that would address threats to and damage already suffered by the lakes. The key points of the plan, which proponents are seeking to incorporate in federal law, are outlined here. Costs are from the strategy.

I. Recovering Coastal Health

Combined sewage overflows, waterborne disease outbreaks and beach contamination plague many Great Lakes coastal waters and pose a threat to public health. In 2005, more than 24 billion gallons of sewage spilled into the Great Lakes.[1] That same year, there were 2,740 days of beach closings or beach advisories.[2] To eliminate discharges of untreated or inadequately treated human and industrial wastes into the Great Lakes Basin by 2020, the restoration plan proposes to:

PHOTO: Healing Our Waters Coalition/Darrald Martin

- provide funding of $50 million over 5 years to support state and community-based coordinating councils in the AOCs and $8.5 million over 5 years to the Environmental Protection Agency's Great Lakes National Program Office for regional coordination and program implementation; and
- fully fund, at $3 million annually, the research and development program authorized in the Great Lakes Legacy Act.

- improve municipal wastewater treatment facilities along the Great Lakes (five year total: $13.7 billion);
- improve drinking-water quality through protection of drinking-water sources ($1.61 billion); and
- develop more rapid and more accurate tests for determining when beach water is safe for swimming ($7.2 million).

II. Repairing Areas of Concern

Drinking water restrictions. Beach closings. Declines of fish and wildlife populations. These impacts are the legacy of toxic pollution in the Great Lakes and its tributaries and harbors. In 1987, the U.S. and Canadian governments identified the most polluted sites around the Great Lakes as "Areas of Concern" – 31 of the 43 sites are located in the United States. More than 20 years since this designation, only one site has been taken off this list in the United States. The GLRC Strategy proposes to restore all Great Lakes Areas of Concern (AOC) by 2020, with interim targets, and recommends that Congress:

- appropriate $750 million over 5 years, under the Great Lakes Legacy Act, to remediate contaminated sediment sites in the Areas of Concern;

III. Cutting Back Non-Point Contamination

Chemicals, fertilizers, pesticides and animal waste from farms, city streets and neighborhood yards degrade water quality of the Great Lakes, as well as its wetlands and tributaries. The Great Lake Regional Collaboration Strategy aims to protect and restore wetlands in urban and rural areas so that all water bodies across the Great Lakes region function as healthy ecosystems. To achieve these objectives, funding is needed to:

- restore up to 550,000 acres of wetlands over 5 years, recognizing that 50 to 70 percent of the region's historic wetlands already have been lost (between $375 million and $944 million);
- restore 35,000 acres of buffer areas in urban and suburban areas ($335 million);
- implement measures to reduce by 40 percent the soil loss in 10 selected watersheds ($120 million);
- support the development and implementation of comprehensive nutrient and manure management on livestock farms ($106 million); and
- achieve hydrological improvements in 10 urban watersheds ($90 million).

IV. Reducing Toxic Pollution

Passage of landmark national environmental protections more than 30 years ago helped reduce the presence of many toxic pollutants in the Great Lakes. However, the presence of fish consumption advisories in all five Great Lakes illustrates how threats to human health and wildlife remain.

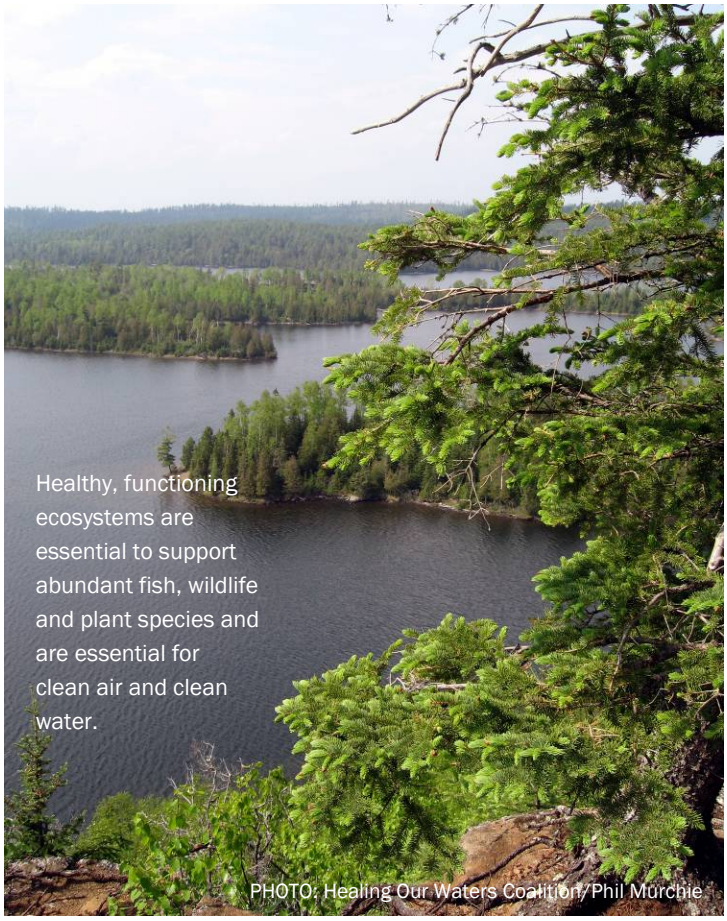
The GLRC Strategy calls for the virtual elimination of persistent-toxic-substance (PTS) discharges into the Great Lakes ecosystem; a significant reduction of exposure to PTS from historically contaminated sources; a reduction of toxic chemicals to levels that permit the elimination of all restrictions on the consumption of Great Lakes fish; and protection of wildlife populations and habitat from the adverse effects associated with the release of PTS.[3] To achieve these objectives, the restoration plan requires funding to:

- virtually eliminate principle sources of mercury, PCBs, dioxins and other toxic substances in the Great Lakes Basin ($60 million);
- prevent new toxic chemicals from entering the Great Lakes Basin ($80 million in spending, $250 million in tax incentives);
- institute a comprehensive research, surveillance and forecasting plan for identifying, managing and regulating chemical threats to the Great Lakes Basin ($25 million to $50 million, in addition to the $1.5 billion likely to be spent already over the next five years);
- launch a public education and messaging campaign relating to the toxic threats associated with fish consumption ($68 million in new spending); and
- support efforts to reduce continental and global PTS sources that contaminate the Great Lakes Basin ($30 million in new spending).

V. Habitat Protection and Conservation

The region has lost more than half of the region's wetlands and 60 percent of the region's forest lands. The loss and degradation of habitat has led to plant and animal extirpations and has damaged the ability of the lakes to resist additional stressors such as pollution and invasive species. A healthy, functioning ecosystem is essential to maintain sustainable and diverse populations of fish, wildlife and plant species and plays a critical role public health—contributing to clean air, clean water and stabilized soil.

The plan aims to restore and preserve habitats and native species in the lakes themselves, to maintain the full range of ecosystem services in area wetlands, to ensure sustainability of basin streams, rivers and tributaries and to restore coastal shore habitats and the processes that sustain them.[4]



Healthy, functioning ecosystems are essential to support abundant fish, wildlife and plant species and are essential for clean air and clean water.

PHOTO: Healing Our Waters Coalition/Phil Murchie

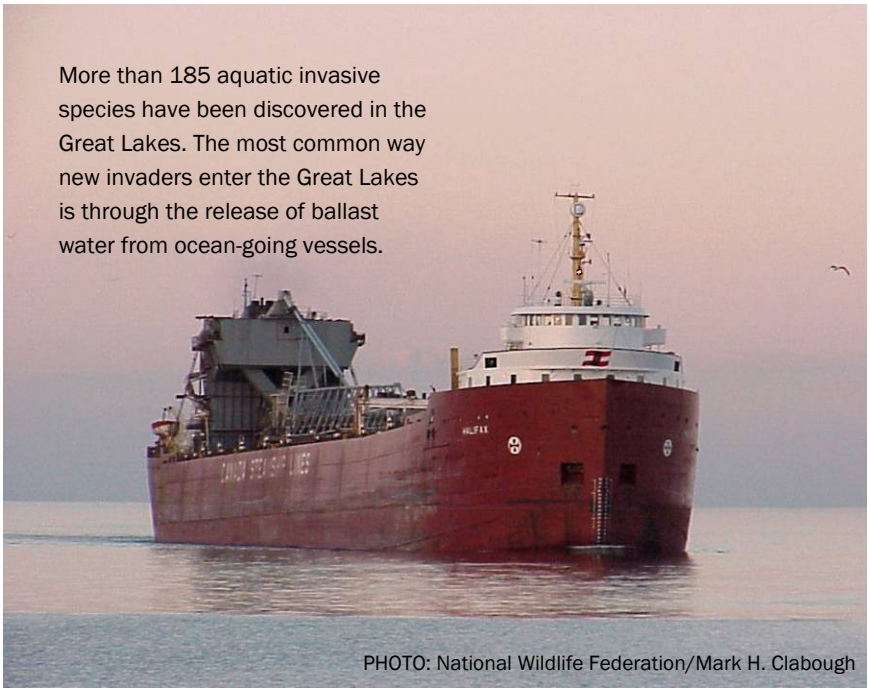
To accomplish these goals, the strategy recommends:

- an increase in habitat conservation and special management funding by $289 million yearly, for a five-year total of $1.45 billion.

VI. Addressing Aquatic Invasive Species

Aquatic invasive species like the zebra mussel wreak havoc on the environment, economy and quality of life. More than 185 aquatic invasive species have been discovered in the lakes. One new non-native species is discovered, on average, every 28 weeks. To stop the influx of invasive species, the GLRC strategy sets two goals: 1.) to prevent all new introductions, and, 2.) to halt the spread of existing invasive species within the lakes—or, if that goal proves impossible, then to keep them at levels which ensure that ecosystems and the social, economic and cultural uses they support are sustainable.[5] To achieve these goals (five-year cost estimates are provided in parentheses), the strategy report recommends that:

- efforts be made to eliminate and/or control the spread of invasive species by ships and barges ($66 million);
- federal, state and local governments enact measures—including full federal funding of the Chicago Sanitary and Ship Canal barrier—to ensure that invasive species are not introduced through the basin's canals and waterways ($225 million);
- federal and state governments implement measures preventing the introduction and spread of invasive species through the trade and potential release of live organisms ($85 million);
- an invasive species management program be established to implement rapid response and control ($220 million); and
- outreach and education programs be designed and aimed at recreational and other users of the Great Lakes ($98 million).



More than 185 aquatic invasive species have been discovered in the Great Lakes. The most common way new invaders enter the Great Lakes is through the release of ballast water from ocean-going vessels.

PHOTO: National Wildlife Federation/Mark H. Clabough

VII. Develop a System of Indicators and Information

The Great Lakes are vast and complex. To succeed in restoring them, resource managers, elected officials and stakeholders need the consistent monitoring and measuring of key indicators of ecosystem function. Current efforts, however, are under-funded, lack comprehensive ecosystem approaches and exist as piecemeal programs.[6] To ensure adequate tracking of lake health, the restoration plan recommends a series of measures aimed at collecting, analyzing and disseminating key information, including a two-fold increase in the current Great Lakes research budget and an increase in the involvement of universities.

The total estimated cost for these measures is $350 million over five years.

VIII. Assuring Sustainable Development

The restoration plan includes a series of measures aimed at assuring that further development in the Great Lakes Basin is environmentally sustainable. Toward this end, the collaborative strategy recommends that:

- state and local governments in the region encourage sustainable development;
- state and regional planning and governance be aligned to enhance sustainable planning and management of resources ($115 million);
- marketing and outreach programs be launched to educate consumers and users on sustainable alternatives ($10 to 20 million); and
- adequate resources be provided to implement this overall strategy ($30 million).

IX. Restoration Costs and Benefits

Total cost is an estimated $26 billion, according to the Brookings Institution.[7] However, the region will gain an estimated $50 billion in long-term economic gains and $30 billion to $50 billion in short-term economic activity from lake cleanup. (see page 10 for more info.)

Restoring the Great Lakes can be a boon for cities like Detroit, above, which stand to gain billions of dollars through increased property values.

PHOTO: Sierra Club

Healthy Waters Yield a Strong Economy

Great Lakes states have entered a time of economic transition, moving from an industrial and agricultural based economy to a knowledge-based economy. "The Great Lakes and their abundant fresh water offer a doorway to this new economy,"[99] but only if the lakes are healthy and the water clean.

The Brookings Institution published a study in 2007 that described the total economic impact of cleaning up the lakes. The Brookings paper indicted that if governments provide full funding for the restoration plan during the next five years, as recommended by the Great Lakes Regional Collaboration Strategy, the nation can expect at least a $50 billion annual return, but more likely something in excess of $80 billion. The report revealed that Great Lakes restoration would yield numerous, specific economic benefits. For example, restoring the lakes:

- leads to direct economic benefits of $6.5 billion to $11.8 billion from tourism, fishing and recreation alone;
- raises coastal property values $12 billion to $19 billion by remediating designated areas of concern;
- reduces costs to municipalities by $50 million to $125 million by reducing sedimentation; and
- produces additional unquantifiable but significant economic activity by making the region more attractive to business and workers.[100]

Additionally, the Brookings Institution conducted a follow-up study in 2008 that lists the specific benefits to fully funding the Great Lakes Regional Collaboration Strategy for the eight largest metropolitan areas in the region. Not surprisingly, the biggest cities see the biggest benefits. For example, Chicago's estimated benefit is between $7.4 billion and $13.3 billion. However, even smaller communities like Duluth, Minnesota, and Erie, Pennsylvania, will see between $200 million and $500 million in benefits from Great Lakes restoration.[101]

As already noted, climate change exacerbates the problems facing the lakes. If governments and communities ignore these problems, the resources that support the Great Lakes regional will decline, and the economic benefits identified by the Brookings paper could be dramatically reduced. Heavier rains mean more storm-water-sewer overflow discharges leading to waterborne disease outbreaks and beach closings. They also mean greater runoff from farm fields and city streets, dumping higher levels of fertilizers into lake waters and causing increases in algal growth and dead zones. Lower lake levels will expose toxic sediments to the wind, or increased dredging will distribute the sediments from where they now are isolated on lake bottoms. Warmer temperatures and warmer water will attract new aquatic invasive species to clog pipes and out-compete native fish for food.

Fixing these problems is key to achieving the economic benefits that will accrue from restoring the Great Lakes. Failing to address these problems—failing to provide the full $26 billion for restoration called for by the Great Lakes Regional Collaboration over the next five years—means that the "health of the lakes will continue to deteriorate, and the costs associated with their restoration will continue to rise."[102]

PHOTO: National Wildlife Federation/Adam Theriault

I. Changing Climate in the Great Lakes Region

The Great Lakes region is expected to experience significant warming during the twenty-first century, especially if greenhouse gas emissions continue unabated. Climate models project that daily high temperatures in the region will increase by 5.4 to 10.8 degrees Fahrenheit relative to what was typical from 1961-1990.[12] Wintertime temperatures could increase even more than summer temperatures.[13] Winters are already growing shorter in the Great Lakes region, with the last spring frost coming about a week earlier than it did in the early 1900s.[14] This trend will continue, with some models projecting that the growing season will start as much as 15 to 35 days earlier each spring and that the first autumn frost will arrive up to 35 days later.[15]

Warmer winters will mean significantly less ice cover on the lakes. A study by the Union of Concerned Scientists projects 33 to 88 more ice-free days on Lake Superior by 2090.[16] By that year, most of Lake Erie is projected to be ice-free during winter 96 percent of the time.[17]

Precipitation also will be affected by global warming. Climate models suggest that precipitation will shift seasonally in the Great Lakes region, with up to 30 percent more rain and snow in winter and spring and similar decreases in summer and fall.[18] When it does rain or snow, the region is very likely to experience heavier precipitation events.[19] Heavy rainfall events are projected to double by the end of the century.[20] Warming climate also could yield more lake-effect snow as lake-water temperature increases and the area of lakes covered with ice decreases, allowing for storms to pick up more moisture.[21]

PHOTO: Healing Our Waters Coalition/Jennifer Vipond

Great Lakes water levels are influenced by several factors, including how much precipitation the region receives and how much water evaporates from the lakes, both of which may be affected by global warming.[22] Typically, lake levels drop after especially hot years, when warmer temperatures and less ice cover promote more evaporation. For example, lake levels were especially low after the 1988 drought and after the unusually warm conditions in 1998. Lake levels also are affected by the system of locks, hydropower plants and outflow control mechanisms regulated by the International Joint Commission and other management bodies.[23]

Most climate models project that Great Lakes water levels will drop during the next century.[24] In the analysis of results from a dozen scenarios with a range of models, 10 out of 12 cases show lower water levels for Lakes Huron and Michigan; 10 out of 11 for Lake Superior. By 2050, based on a model developed by the Canadian Centre for Climate Modeling and Analysis, levels could decline by approximately 1 foot on Lake Superior, 3 feet on Lakes Michigan and Huron, 2.7 feet on Lake Erie and 1.7 feet on Lake Ontario.[25] Because of its shallowness, the shoreline impacts on Lake Erie could be dramatic. According to the most recent Lake Erie Lakewide Management Plan report, the lake's surface area could shrink by up to 15 percent by late in the twenty-first century, exposing nearly 1,500 square miles of additional land.[26]

II. Impact of Global Warming on the Great Lakes Ecosystem

A. More and Larger Biological Dead Zones

Northern lakes currently go through important physical changes through the course of the year. Water separates

into two major layers in summer and winter (i.e., warmer, lighter waters over colder, deeper waters in summer), and then mix when temperatures of the top and bottom layers are the same in fall and spring. This mixing ensures the redistribution of oxygen-rich waters, a process called "lake turnover." Without turnover, lake bottoms could become biological dead zones because the decay of organic matter, produced in the surface and settled to the bottom, uses up the oxygen. Global warming is changing the timing of turnover and lengthening the duration of stratification, potentially reducing available oxygen and nutrient supplies and jeopardizing fish and other aquatic life. For example, summer surface water temperature increases in Lake Superior from 1979 to 2006 have caused summer stratification in the lake to start earlier by roughly half a day per year over this period.[27]

Most lakes in the Great Lakes region exhibit the stratification patterns discussed above, with reduced oxygen levels in deeper waters during summer stratification. Very serious reduction has long been the case in Lake Erie's Central Basin, where a dead zone of very low oxygen levels appears every summer. The extent of this dead zone decreased after implementing phosphorus control measures in the 1980s; however, its recent increase may be tied to climate-driven changes in temperature and precipitation patterns. Climate models predict that the extent and persistence of these low-oxygen zones will continue to increase with warming, posing threats to aquatic life. In addition, some research indicates that warming may also increase productivity (i.e., growth of plant and animal life) due to an increased ice-free period, increased water temperature and longer growing season.[28] This increased production will rain more organic matter to the bottom, fueling larger dead zones. While Lake Erie is known for its dead zone, Lakes Ontario, Superior and Michigan would be most sensitive to oxygen depletion in deeper waters following a warmer climate, threatening some cold water fish species.[29]

Other research has also suggested that lake productivity could decline due to light- and nutrient-limitations caused by deeper surface layers and reduced seasonal mixing.[30] Model projections indicate that the most dramatic changes in limitation would be for Lakes Superior, Michigan and Huron, with the largest relative changes in Lake Superior. Decreases in primary production (i.e., of phytoplankton) would mean less food available for zooplankton and for the prey of predator fish. This pressure on the lower part of the food web would come in addition to steep declines—more than 90 percent in part of Lake Michigan—of the tiny sediment-dwelling shrimp *Diporeia*, which constitutes a significant fraction of the foundation of the Great Lakes food web.[31] In other words, warming water may devastate the ability of the lower Great Lakes food web to provide for the fish, wildlife and people that depend on them.

PHOTO: Healing Our Waters Coalition/Melisa Schamburek

B. Competition for Water

As global warming leads to predicted declines in the planet's freshwater supplies, more eyes will turn to the Great Lakes as a potential source of freshwater. Existing pressures to supply freshwater to areas that lie outside the natural Great Lakes watershed are likely to increase in the face of more and longer droughts. Projections indicate that in the wake of global warming, the Great Plains and the Rocky Mountain region will face decreasing water supplies in response to shrinking winter snowpack and early spring runoff. As a result, water-dependent agriculture and industry may shift toward the Great Lakes region as the costs of irrigation and industrial water become more prohibitive in drier locales. Legal structures such as the Great Lakes Compact, which will establish the rules for Great Lakes water uses, will become essential tools for managing water resources.

C. Contamination of Beaches and Shorelines

Untreated sewage, such as that frequently washed into the Great Lakes following major summer storms, carries an unhealthy mix of bacteria and high levels of nitrogen that can yield an unpleasant sewer smell, black waste plumes spreading across lake waters, contaminated beaches and even odiferous algal blooms from the fertilizing effect of nitrogen and phosphorus. As a result of such

The Great Lakes Compact

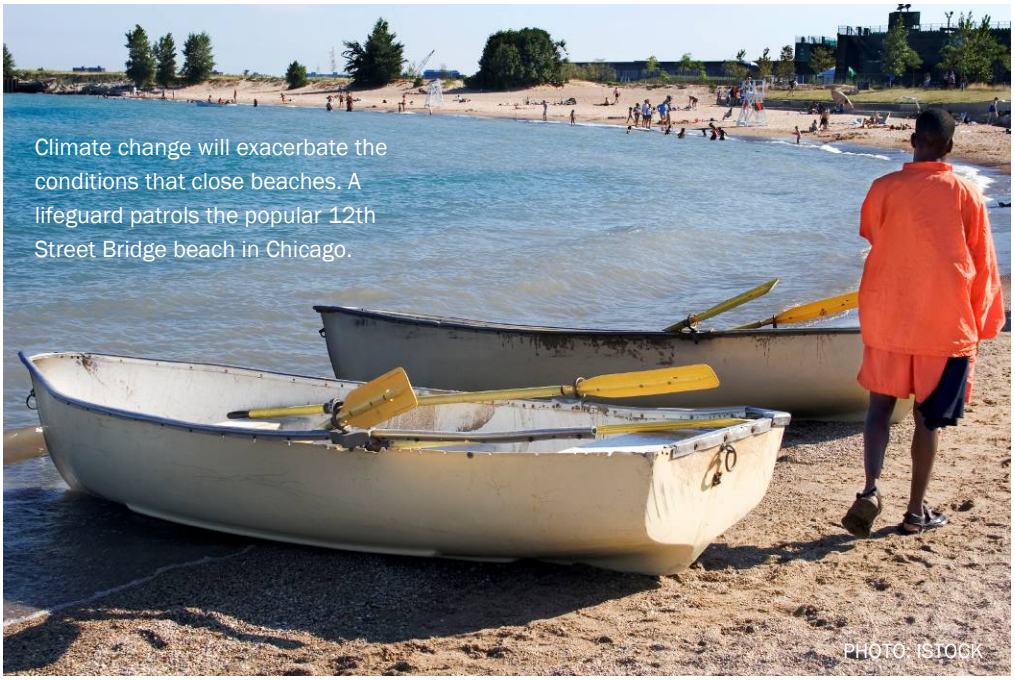
Annual rainfall, snowmelt and groundwater recharge replace only about 1 percent of the water in the Great Lakes Basin each year. The other 99 percent is nonrenewable. Once it's gone, it's gone. Consequently, as the Great Lakes evaporate more quickly because of global warming, lake levels are likely to drop. Growing demand for water for domestic uses—including utilities, agriculture, manufacturing and housing within the Great Lakes region and in drier parts of the nation—compounds concern over the future of the lakes, especially because current laws are not strong enough to protect them.

In December 2005, after nearly five years of negotiations—combined with input from citizens across the region—the eight Great Lakes governors endorsed an agreement to protect and preserve the Great Lakes. In the Great Lakes-St. Lawrence River Basin Water Resources Compact, the governors agreed to prohibit diversions of Great Lakes water outside the basin. The Compact also:

- ensures that every Great Lakes state will be subject to the same protections while allowing each state the flexibility necessary to manage its own water use;
- puts much needed water conservation and resource protection into a proactive public law regime;
- establishes protection of Great Lakes ecosystems and economies everywhere in the basin; and
- ensures that the Great Lakes states and provinces work together to manage water resources adaptively as new scientific information regarding global warming impacts becomes available.

Language consistent with the Compact must be adopted through legislation by the eight Great Lakes states and then by the U.S. Congress. As of this report, four of the states (Illinois, Indiana, Minnesota and New York) had adopted the Compact into law, and in three others Compact bills had passed one legislative chamber.[32]

Climate change is certain to put additional stress on freshwater resources across the United States. The Great Lakes Compact establishes a comprehensive, regional water policy to protect the Great Lakes from diversion and overuse.



Climate change will exacerbate the conditions that close beaches. A lifeguard patrols the popular 12th Street Bridge beach in Chicago.

PHOTO: ISTOCK

contamination, in summer 2005 residents in the Great Lakes area lost almost 3,000 beach days due to closings or health advisories (a beach day is a single day on which a beach is open; for example, if a region has 500 beaches, each day that all those beaches are open constitutes 500 beach days). Great Lakes beaches in popular metropolitan areas, along northern Lake Michigan and even along Lake Superior have been affected in recent years.

Climate change will exacerbate the conditions that result in beach closings because:

- More severe storms—as predicted by climate models—suggest more runoff in city streets, more sewage overflows and more untreated sewage dumped into the Great Lakes and their tributaries. It also means more runoff from farm fields treated with pesticides and fertilizers.
- Warmer water combined with other factors can lead to algal growth that fouls beaches and can threaten human health. For example, recent years have seen an increase in the growth of the alga Cladophora in some Great Lakes shoreline areas. While reasons for the increase are not understood, it is known that the increased water clarity from zebra mussels increases suitable Cladophora habitat. In addition, some of the increase may be due to factors related to climate, such as warmer water and water-level drops exposing additional shallow water habitat.[33] Cladophora beds compound pollution problems because they can host higher concentrations of pathogenic bacteria from such sources as stormwater runoff and bird droppings.[34]
- Environmental changes leading to increased Cladophora abundance also can contribute indirectly to fish and bird mortality. Recent years have seen increasing bird die-offs in the Great Lakes due to avian botulism, including the more typically pristine beaches of Sleeping Bear Dunes in

Protecting Citizens

Safeguarding human health is a shared responsibility of federal, state and local governments. People need to be protected from water-borne bacteria when shorelines are polluted by runoff, sewer overflows or other sources. Congress passed the Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000 to help local authorities monitor beach-water quality and develop public notification programs on beach safety related to concentrations of unhealthy bacteria. Funding for the BEACH Act and required monitoring activities will be important as Great Lakes beaches expand because of lower water levels, and as the possibility of increased frequency of extreme weather events leads to increased discharge of microbial pollutants into nearshore areas.

northern Michigan. Though biologists are still investigating the mechanisms leading to increased levels of the bacterium responsible, factors that appear to be involved include zebra mussel colonization; Cladophora and the low oxygen conditions that result from decaying organic matter; uptake through the food web, including invasive round gobies; and consumption of fish, including carcasses, by birds. Species subject to die-offs have included waterbirds such as horned grebes, double-crested cormorants and the endangered piping plover.[35]

D. Increases in Shoreline Conflicts

A projected drop of 1 to 3 feet for lakes Michigan and Huron could expand many beaches by 100 feet or more. Public ownership of the newly exposed beaches would result in public access to areas that private lakeshore property owners may want to keep under their control, leading to claims and counterclaims of ownership by the public and private sectors, as has occurred already in Ohio and Michigan. On a positive note, however, one scientist says, "We could very well have very wide beaches. It might make the Great Lakes much more attractive recreationally."[36] One state official says that reduced water levels could re-create a natural shoreline for Lake Erie. "We can try to be positive about climate change, really positive," said Jeff Tyson, a senior fisheries biologist at the Ohio Department of Natural Resources, who helped write a portion of the 2006 Lake Erie management plan. "If it continues to be hot, once you lose that meter of water over the top, we get an entirely natural, new shoreline along a lot of the lakefront. If we manage it right, things could look a lot like they did when the first white settlers arrived."[37]

E. Degraded Water Quality and Jeopardized Wildlife

More than 30 million people rely on the Great Lakes and their tributaries for drinking water. The lakes support countless species of fish and other wildlife. But people and wildlife will be increasingly at risk as a changing climate degrades Great Lakes water quality.

Many of the toxic materials that will contaminate beaches and shorelines, such as increased polluted runoff and exposed toxic hotspots, also will worsen water quality generally. In 2003, the International Joint Commission's Water Quality Board identified the following potential impacts of climate change on Great Lakes water quality:

- increased taste and odor problems in drinking water;
- prolonged periods of thermal stratification, with associated declines in dissolved oxygen;
- changes in mixing depth that affect productivity;
- increased non-point source pollution from higher intensity precipitation events;
- significantly higher costs in meeting water-quality goals; and
- failure to meet water-quality remediation targets.[38]

The report indicated that increased water temperatures may lead to more frequent and widespread algal blooms, possibly causing an increase in "fishy, grassy, or earthy-musty" odors in drinking water. Although treatable, this effect would lead to higher costs for water suppliers.[39]

Rising water temperatures and lower water levels also may increase the mobility of toxic chemicals already in lake water and sediments. Lower water levels could expose

Seeking Cleaner Lakes

Cleaning up environmental pollutants becomes critical as the Great Lakes change from global warming, and toxic sediments are exposed. Congress passed the Great Lakes Legacy Act in 2002 as the main federal program to address the toxic contamination resulting from the region's industrial economy. More funding for the Legacy Act is critical to speed the clean up of toxic sites throughout the region for the benefit of the environment and the economy.

formerly submerged toxic sediments contaminated with PCBs, mercury and dioxins—exposing beaches, shorelines and the people who use them to higher levels of dangerous chemicals. In addition, warmer conditions, such as those in recent El Niño years, have been linked to higher concentrations of persistent organic pollutants such as lindane and polychlorinated biphenyls (PCBs), around the Great Lakes.[40] Already, PCBs released from Lake Michigan's sediments and water re-contaminate surface waters elsewhere in the Great Lakes when carried by precipitation or wind.[41] Increased atmospheric redistribution of these persistent toxic chemicals spells new dangers to aquatic food webs, whether in the Great Lakes region or the wider global environment.

As was already noted, scientists predict that, in the wake of global warming, Great Lakes weather patterns are likely to continue to shift toward more intense thunderstorms and downpours instead of steady, gentle rains. This change will significantly increase soil erosion and the delivery of both dissolved and sediment-attached pollutants such as nitrates, phosphorus and pesticides to tributaries and the Great Lakes. The influx will be particularly challenging in spring, when vegetative cover is at a minimum and increased precipitation likely. It also will increase the intensity of street runoff and the likelihood of combined sewer overflows—already a major source of nutrient, bacteria and pathogen pollution in the lakes.

The United Nations-sponsored International Panel on Climate Change (IPCC) recently concluded that beach closures will likely increase as the amount of pollutants in the Great Lakes grows more concentrated in the wake of shrinking water levels and that municipalities that draw water from the lakes will face increasing water-quality problems. "Lower water levels in the Great Lakes are likely to influence many sectors, with multi-dimensional, interacting impacts."[43] The Buffalo News reported that scientists associated with the IPCC study are concerned that contaminants in lake sediments may be returned to circulation in some areas of the Lakes:

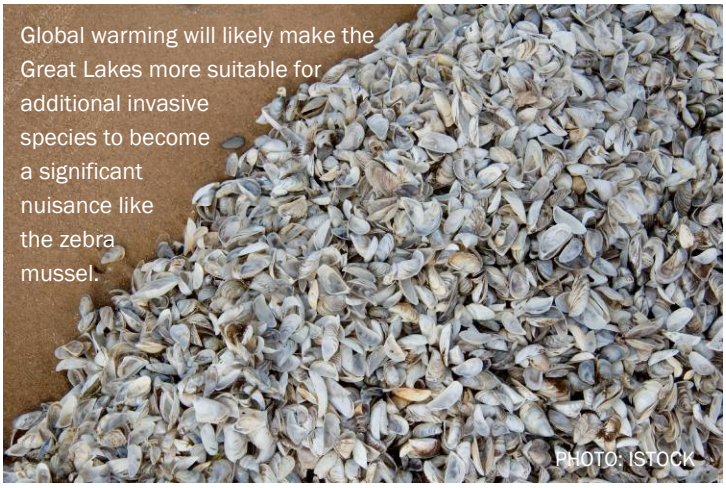
> We've let a lot of chemicals go into the environment in that part of the world, and it is now reasonably contained in the sediments at the bottom of the region's lakes and rivers, [Stanford University Professor Stephen] Schneider said. Lowering the lake levels makes it more likely that those sediments will be stirred up and contaminate the water, he said. And that's why the climate change panel is concerned that global warming could affect everything from municipal water supplies to beach closings to the safety of eating Great Lake fish.[44]

F. More Invasive Species

Approximately 185 invasive species have established themselves in the Great Lakes as of May 2007.[45] Their effects are diverse and expensive. Zebra mussels from southeast Russia have clogged water supply intakes and cluttered beaches with their sharp shells. Quagga mussels

Rising Water Treatment Costs

Given that global warming may yield increased periods of drought, changes in precipitation patterns and greater upstream water demands from communities and agriculture, the International Joint Commission's Water Quality Board has reported that decreased flows in Great Lakes tributaries could lead to degraded water quality or to increased costs for municipalities and industry for water treatment. This change would also make attainment of remediation goals for polluted bays and harbors much more difficult. According to a 2007 report by the United Nations' Intergovernmental Panel on Climate Change, "In the Great Lakes and major river systems, lower levels are likely to exacerbate challenges relating to water quality, navigation, recreation, hydropower generation, water transfers and bi-national relationships."[42]



Global warming will likely make the Great Lakes more suitable for additional invasive species to become a significant nuisance like the zebra mussel.

from Ukraine have promoted the growth of bacteria responsible for Type E botulism, resulting in mass fish and wildlife kills. Lake whitefish are declining, as is the value of this important commercial fishery, and a big part of the reason may be significant decline of their primary food source, the native *Diporeia* shrimp species, in response to high numbers of zebra and quagga mussels. These invasive mussels also are changing phosphorus cycling in the lakes through their digestion and excretion, resulting in an increase in algal blooms.

Global warming "exacerbates the invasive species problem" in the Great Lakes, according to researchers.[46] Except for Lake Erie, the Great Lakes functioned for centuries as cold, clear, oxygen-rich systems. "These cold ecosystems favoured native salmonid and corregonid [e.g., lake trout and whitefish, respectively] species in deep waters and walleye, northern pike and perch in the cool-water littoral zones."[47] Warm-water species reached their northern limits in the Great Lakes. Thanks to warmer summer surface temperatures and decreased ice cover, shallow-water habitats are becoming more suitable for invasive species such as several Asian carp species (which have yet to enter and become established in the lakes), zebra mussels and round gobies, which are bottom-dwelling fish from central Eurasia that came into the Great Lakes in the ballast water of cargo ships, as did zebra and quagga mussels.

G. Damaged Wetlands

Wetlands not only provide habitat for fish and wildlife but also serve as the kidneys of the Great Lakes, filtering pollution out of waters running into the lakes and creating a buffer system that allows the lakes to recover from stress. Global warming, however, is likely to dramatically alter wetlands and the protections they offer the lakes. Some climate models predict that as global warming increases, wetlands along some rivers are likely to dry out (i.e., if precipitation decreases substantially), eliminating important habitat and allowing more pollution to reach rivers and other streams. Wetlands in coastal areas of the Great Lakes will convert into uplands as water levels decline, jeopardizing the survival of local wetlands wildlife, depending on the speed with which the wetlands shrink. Large wetlands will become small wetlands, and small wetlands will become dry land. Declining lake levels will also expose more bottom lands to invasive species like Phragmites.

Global warming will force many wetland species to shift geographic range. Earlier drying of ephemeral wetlands could significantly undermine populations of wood frogs and amphibians. Lower water levels could lead to greatly reduced assimilation of nutrients and human and agricultural wastes by wetlands.[48] Decreases in water levels could expose organic wetland soils and release metals such as cadmium, copper, lead and zinc.

H. Fish and Wildlife at Risk

Changes in the viability of recreational fishing could help undermine the Great Lakes' regional economy. In 1991, an estimated 2.5 million U.S. anglers fished the Great Lakes for a total of 25.3 million days of fishing. Lake Michigan accounted for nearly 9.9 million days of fishing, or almost 40 percent of that total. The estimated value (in 1993 dollars) of one day of freshwater fishing for trout was $16.52 in Michigan, up to $47.92 in Minnesota and $32.29 in Wisconsin. One study estimated an annual loss of $320 million because of the lower value anglers place on the warm-water species that would displace, to some extent,

Great Lakes native cool- and cold-water fish.[49] A forecast warming of 4.5 degrees F during the next 70 years would reduce the habitat of brook, rainbow, cutthroat and brown trout by one-fourth to one-third. Pennsylvania, New York, Ohio, Indiana and Illinois would collectively lose 86 percent of their rainbow trout habitat.

Warmer winters mean less ice, which harms fish production and Great Lakes fishing in many ways. "The formation of ice over the shallow waters where whitefish spawn protects their eggs from destructive wind and wave action," according to biologists at the Great Lakes Environmental Research Laboratory. "A reduced ice cover could mean greater mortality of the eggs and thus could potentially lower year-class strength." Microscopic algae that are the basis of the food chain, supporting all other life, including commercial and sport-fish species, benefit from clear ice cover with little or no snow cover. Light penetrates through the clear ice promoting algal growth in the stable, near-surface waters.[50]

Damaged Economies

Ice fishing has been affected for a few seasons now, said Steve Koski, owner of Indian Country Sports in L'Anse, Michigan. "People want to ice fish, but they have had a tough time in the last many years. The ice is getting less predictable." During the unusually warm mid-winter of 2006, a lack of ice on Lake Erie meant the near collapse of a normally robust ice-fishing industry and of the businesses that support ice fishing, which involves cutting a hole in surface ice and fishing from a set position. The New York Times reported guides at Ohio's Put-in-Bay tried boat fishing, but strong winds whipped up sediment and clouded the water so much that fish could not see the lures. "I'm down $40,000," said guide Bud Gehring. "It's hurt everybody."[51] A bed-and-breakfast owner failed to rent a room all winter.

Reduced Great Lakes levels could also shrink or dry up coastal wetlands that provide a breeding ground for fish and wildlife, notably waterfowl.[52] In 2001, Minnesota, Wisconsin and Illinois were three of the top 10 states in expenditures for migratory bird hunting.[53] The National Wildlife Federation notes that research has indicated that changes in breeding and migratory habitat associated with global warming could lead to declines in duck populations around the Great Lakes from19 to 39 percent by 2030.[54]

I. Diminished Forests

Climate change is likely to impose damaging ecological changes on native forests. In Minnesota, mixed forests adapted to warmer conditions could replace the unique boreal forests in the northern part of the state and in the Boundary Waters Canoe Area Wilderness. The diverse aspen, birch, beech, maple and pine forests in the northern and eastern areas of the state would shrink in range, replaced by a combination of grasslands and hardwood forests consisting of oak, elm and ash. "Grasslands and savanna eventually could replace much of the forests and woodlands in the state. These changes would significantly affect the character of Minnesota forests and the activities that depend on them," according to the Minnesota Pollution Control Agency.[55] A similar fate may await Michigan forests, which could decline as much as 70 percent.[56]

Most climate models predict that higher air temperatures will cause greater evaporation and reduced soil moisture, promoting forest fires. "There will be an increased likelihood of greater environmental stress on both deciduous and coniferous trees, making them susceptible to disease and pest infestation, likely resulting in increased tree mortality."[57] Native forest biological diversity will likely decline, threatening the health of forest ecosystems. The forested watersheds of the Great Lakes play a critical role in providing habitat and protecting water quality in Great Lakes tributaries, especially in the Lake Superior basin. As the forests change, so will the waters of the Great Lakes Basin. "There is no market mechanism to value and

protect forests for their biological diversity, nor do we have tried and tested strategies to maintain important plant and animal species under a changing climate," one researcher wrote.[58]

Forests already under stress from warmer conditions and periods of drought also face increased risks from pests formerly killed off by severe winter temperatures. Jack pine budworm, killed by sharp cold, is worsening. "After it molts six times, it over-winters as a very small larvae just under the bark of the host tree," says Al Keizer, forest-health monitoring officer with the Canadian Forest Service office in Sault Ste. Marie. "Milder winters mean more survive and that may mean they overwhelm natural predators and diseases."[59]

Another pest surviving the milder winters is the gypsy moth, said Kathryn Nystrom, an insect-identification officer with the Great Lakes Forest Centre. Extreme conditions of prolonged cold also can kill unprotected gypsy moth eggs, she observed, but persistent temperatures of minus 22 degrees F are occurring less frequently.

Protecting Wildlife and Habitat

When habitat has been damaged or disappears, it has a ripple effect on the species that depend on it. Many Great Lakes fish are in decline from a combination of habitat loss, pollution and invasive species. Yellow perch have been a popular game fish in Lake Michigan, but the population declined significantly starting in the late 1980s/early 1990s due to poor recruitment, and has still not fully recovered. For example, in Wisconsin waters of the lake, the commercial fishery was closed in 1996, and while sport fish catches in Green Bay have increased in the past few years, catch rates in Lake Michigan (apart from Green Bay) have averaged well below numbers in the early 1990s. Commercial (and recreational) harvesting of whitefish has continued in recent years, but there is concern about sustainability, due to the significant loss of *Diporeia* populations in the lake. Restoration efforts for species such as lake trout and lake sturgeon continue, but achieving self-sustaining populations (while stresses such as invasive species and habitat limitations persist) remains a challenge.[60] Perhaps the most dramatic recent changes have occurred in Lake Huron, where prey fish species, including alewives, rainbow smelt and bloaters, have declined significantly since the mid 1990s. In addition, while catches of some Lake Huron species of interest to sport and commercial anglers, such as lake trout, have increased recently, other species, including perch, Chinook salmon and brown trout, have seen dramatic declines in recent years.[61] While changes to the lower food web are likely responsible for some of these changes, climate change would pose additional problems for an already stressed system.

Lakes habitat programs—such as the Great Lakes Fish and Wildlife Restoration Program, which is a U.S. Fish and Wildlife Service competitive-grants program that funds restoration work in the Great Lakes Basin, and the Great Lakes Fishery and Ecosystem Restoration Program, which is a U.S. Army Corps of Engineers equivalent that targets projects at which the Corps is especially adept, such as dam removal—can help reduce damage to the Great Lakes environment and help it adapt to coming changes. In order to adapt to the changes that global warming will bring to the Great Lakes environment, more funds will be necessary for these and other federal agencies, including the National Oceanic and Atmospheric Administration (through its Coastal Zone Management Program, Sea Grant, and its related research programs) and the Natural Resources Conservation Service.

J. Challenges and Losses for the Shipping Industry

Lowered water levels would have major implications for the Great Lakes shipping industry and for taxpayers. According to one study, the need for increased dredging of waterways to permit passage of commercial vessels could cost $75 million to $125 million annually.[62] Additionally, the Lake Carriers' Association (trade association of companies with U.S.-flagged ships on the Great Lakes) has indicated that a 1,000-foot- long vessel loses 270 tons of cargo-shipping capacity for every inch of lowered water,[63] and the president of the United States Great Lakes Shipping Association said in 2006 that for every inch drop in water levels, ships bound for destinations outside North America forfeit about $8,400 in freight revenue. Lake Superior's largest American ships carried 3,000 fewer short tons of cargo in 2005 than in 1997, when water levels were 12 inches higher, according to the Lake Carriers' Association.[64] The effect of even more-significantly lowered water levels would be "devastating," said Wayne Smith of Seaway Marine Transport. "Climate change is most definitely an issue for us."[65] As noted previously, levels in Lake Superior reached record lows in September and October of last year, reducing shipping capacity even further.[66]

A 2002 paper outlined additional potential impacts of climate change on Great Lakes shipping, including increases of up to 30 percent in shipping costs from reduced cargo and increased trips as well as water-quality risks from dredging contaminated sediments to deepen shipping lanes. The paper also noted, however, that reduced ice cover could promote a longer shipping season.[67]

Lake Superior: Canary in the Coal Mine?

The largest and coldest of the Great Lakes, Superior is drawing increased scientific attention because of what appears to be rapid warming and significant lowering in response to global warming. The lake "is in its largest stretch of below average water levels since we've been recording water levels," said a U.S. Army Corps of Engineers official in August 2007.[68] Precipitation in the basin has been down, and reduced ice cover in the winter has increased evaporation. Monthly average levels in the lake for August and September 2007 were record lows for those months, surpassing previous marks of 1926. Although above-average precipitation in September and October pushed levels back up above record lows, water supplies to the basin were still below average for all of 2007.[69]

During a longer period, the average water temperature of the lake has increased about 4.5 degrees F from 1979 to 2006, "significantly above the 2.7-degree rise in the region's air temperature during the same period." A weather buoy in the western lake reported a temperature of 75 degrees F in August 2007, "as warm a temperature as we've ever seen in this lake," said Jay Austin, an assistant professor at the University of Minnesota's Duluth Large Lakes Observatory.[70] Added Austin: "It's just not clear what the ultimate result will be as we turn the knob up. It could be great for fisheries, or fisheries could crash."

An additional potential threat to the Lake Superior ecosystem is the quagga mussel, a close relative of the zebra mussel with equally significant potential to alter ecosystems. Although the quagga mussel invaded the Great Lakes later than the zebra mussel, it has become widespread in the sediments of Lake Michigan and part of Lake Huron,[71] and in January 2007 was first confirmed in Duluth/Superior Harbor.[72]

K. Impacts on Agriculture

Agriculture "ranks among the most important economic activities in the Great Lakes region, accounting for more than $15 billion in annual cash receipts."[73] An average annual precipitation range between 24 and 42 inches, average 145-day growing season, moderate levels of potential soil evaporation and plant transpiration and adequate levels of sunlight contribute to the region's agricultural success. Among the 120 commodities grown or raised commercially in the region are eight of the world's top-ten food crops.[74] The Great Lakes states of Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin have more than 380,000 farms, encompassing more than 100 million acres of prime land with a total economic impact of $40 billion.

In the near term, at least, increased temperatures, a longer growing season and the increased atmospheric carbon dioxide levels that cause global warming could result in increased yields of some crops.[75] As noted in the National Assessment, "…the effects of increased carbon dioxide concentrations on specific crops of the Great Lakes would differ and often depend on the accompanying temperature and precipitation changes," reports a U.S. government study.[76] In Minnesota, according to U.S. Environmental Protection Agency estimates, corn yields could remain unchanged or could decrease by as much as 34 percent,

Agricultural Programs

The Conservation Reserve Program was first established in the 1985 Farm Bill to provide technical and financial assistance to eligible farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. Subsequent Farm Bills have created other programs that help protect Great Lakes water quality and habitat.

The Wetlands Reserve Program creates wetlands on American farms. Farmers that participate may sell a conservation easement or enter into a cost-share restoration agreement with U.S. Department of Agriculture to restore and protect wetlands. Wetlands on the expansive agricultural lands of the Great Lakes Basin provide important habitat and also provide valuable water-quality services, acting as sediment traps and water filters, as well as sites for groundwater recharge.

The Conservation Security Program provides payments and technical assistance for private and tribal producers that practice good conservation and environmental stewardship on their agricultural lands. The program is designed to reward the best conservation stewards of the most environmentally sensitive areas in targeted watersheds.

The Environmental Quality Incentives Program provides financial and technical help with structural and management conservation practices on agricultural land. Conservation practices may include actions such as protecting and restoring riparian habitats or buffers, erosion control, enhancing wildlife habitat and comprehensive nutrient and manure management.

Each of these programs provides vital ways for preventing nutrients, sediment, and toxic chemicals from entering Great Lakes waters. As temperature and precipitation patterns continue to change these programs will have to expand to ensure protection.

Climate change will impact our nation's food supply. Especially at risk are soybeans which are highly susceptible to climate variability.

PHOTO: ISTOCK

wheat yields could increase by 6 to 10 percent, and soybean yields could be up by as much as 28 percent or down by as much as 12 percent. Other impacts include:

- the likelihood that some weeds are will benefit from increased carbon dioxide, requiring additional herbicide use and related environmental impacts;
- diminished crop yields, resulting from reduced photosynthesis for some crops that are now growing near optimum temperatures;
- reduced quality of some cool-season vegetables and fruit crops affected by brief high temperatures at critical stages of development; and
- increased soil loss from evaporation and reductions in soil moisture.

Global warming is expected to cause significant reductions in yields of some crops and increased hardship for many farmers. "Soybeans are particularly vulnerable to climate variability," writes Michelle Wander, University of Illinois associate professor of soil fertility. "Perennial crops such as fruit trees and vineyards are also vulnerable because adjustments cannot be made as flexibly, putting long-term investments at risk. And the combination of flooding and high heat is especially lethal to both corn and soybeans," she said.[77]

The Union of Concerned Scientists hypothesizes that warming climate, by introducing new pests, could damage Wisconsin agriculture, including nation-leading cheese production and second-place dairy production. "More southerly pests, such as corn earworms, may expand northward. . . . Warming will increase the rate of insect development and the number of generations that can be completed each year, contributing to a build-up of pest populations. Increased pests may drive farmers to use more pesticides or related chemicals, placing an additional burden on water quality."[78]

Specialty crops, such as Michigan's red tart cherries, also could suffer. For example, reduced ice cover on Grand Traverse Bay, adjacent to the state's prime cherry orchards, results in warmer early spring air temperatures that can lead cherry trees to blossom early, making them vulnerable to a freeze.[79] In 2002, the combination of early bloom followed by a deep freeze resulted in a Michigan crop of just a million tons of cherries, compared to an average of more than 140 million tons.[80] Similarly, due to increasingly unfavorable conditions for maple trees and sap production, popular maple syrup production is likely to decline in such states as New York and Michigan.[81] "Once the pride of New York, the maple syrup industry could become a quaint memory."[82]

In the Great Lakes region, "livestock, including dairy, is the number one agricultural commodity group, comprising over half of the total. Dairy production alone produces $5 billion in receipts."[83] But the dairy industry faces its own unique challenges from global warming. "Dairy cattle perform best in cool climates (between 40 and 75 degrees F) and are sensitive to heat stress. High relative humidity, often present in the Great Lakes area, exacerbates heat stress. With 80 percent relative humidity, heat stress for dairy cattle can occur at temperatures as low as 73 degrees F and become severe at 93 degrees F. Moreover, heat stress in dairy cattle can affect reproduction and milk production for as long as 180 days."[84] Cheese makers have discovered that hot and thirsty cows drink more water, which dilutes milk proteins and fat, requiring more milk to make the same amount of cheese and thus increasing cheese production costs.[85]

L. Impacts on Recreation and Tourism

Winter recreation and tourism will likely suffer from a warming climate.

PHOTO: ISTOCK

Outdoor recreation and tourism are significant players in the Great Lakes regional economy. Estimates show that between 900,000 and 1 million U.S. and Canadian registered boats are operated on the Great Lakes each year. Recreational boaters in the Great Lakes region spend more than $2 billion annually on their sport. The region's recreational boating industry, which includes boat manufacturers and retailers, marine operators, marine business suppliers and anglers, accounts for 6,000 private sector marine-related jobs and 10,000 boat dealer and supplier jobs, according to U.S. studies.[86] However, as the lake levels decline, many shallow water harbors that support these activities will no longer be accessible without significant increased dredging.

However, tourism has already changed with the warming climate, and recreational opportunities now taken for granted, such as trout fishing in coldwater streams or cross-country skiing through woodlands, may evaporate with rising temperatures and the advent of extreme weather.

Winter sports are a major source of economic vitality for the region. "Warmer winters mean trouble for states such as Minnesota, where winter recreation has long been an integral part of people's sense of place. Communities and businesses dependent on revenues from cross-country or downhill skiing, snowmobiling, and, especially, ice fishing, could be hard-hit."[87]

While many communities in the lake-effect zones have continued to experience snowy conditions during at least part of the winter season, other areas in the region have struggled to support winter tourism as snow and ice conditions have become less reliable. Lack of snow in 2007 cancelled the John Beargrease Sled Dog Marathon—a 500-mile course along Lake Superior's North Shore. In northern Wisconsin, race officials hauled in snow and halved the duration of the 2007 American Birkebeiner cross-country ski race because of warm temperatures.[88] They also have shortened and altered the course in other recent years to make the continuity of this 35-year Wisconsin tradition possible. Such cancellations and changes affect not only participants. The ripple effect on hotels, restaurants, equipment vendors and other businesses has hit many northern communities hard.

Snowmobiling, a pillar in the winter economy, has dried up in many areas. In 2004, the Michigan Land Use Institute reported, ski resort operators in northern Michigan said the average length of the winter season had shrunk about a week in recent years, from 127 days in the 1980s to fewer than 120 days. "When I first came here in 1985 we had more natural snow earlier in the season," said Jim MacInnes, the general manager and chief executive officer of Crystal Mountain, which attracts thousands of skiers each year to its slopes in Benzie County. "It got cold earlier in the season. Normally we'd be open in the first week of December. Now it's usually a week or two later."[89]

The Michigan Land Use Institute also reported reduced snowmobile sales. In 2004, the International Snowmobile Manufacturers Association said 14,353 new sleds were sold

in Michigan that year, down by almost 50 percent from 27,000 in 1995. "Owners of motels, restaurants, and other services in northern Michigan resort towns confirmed in interviews that their snow sports business is declining. In some cities the change is dramatic: The number of winter visitors to Cadillac, for instance, fell to 23,000 this year from more than 50,000 in the 1980s, according to the Cadillac Area Chamber of Commerce," the Institute declared.[90]

In Michigan's Keweenaw Peninsula, warm early winter weather depressed tourism so much that the Keweenaq Peninsula Chamber of Commerce looked into economic disaster assistance on behalf of affected businesses. Snowmobile trails north of Houghton lacked serviceable snow until about mid-January, and the ski hills did not get 100 percent of their runs open until February.[91]

A Flint newspaper found that declining snow cover was also reducing snowmobile sales. "The true snowmobiler is always going to find snow no matter what. But it seems every year less and less people are snowmobiling and are switching to other alternatives like quad runners," said a dealer. "We've shifted our business dramatically through the last 10 years because of the weather."[92]

After several disappointing winter seasons, the executive director of the Hayward, Wisconsin, Chamber of Commerce concluded: "The lack of snow has forced us to look at other industries." As a regional business newsletter reported, "The area traditionally has depended on snowmobilers and cross-country skiers, but a snow shortage over recent winters has compelled the chamber to look into other ways to draw other groups. In January of 2007 it sponsored a bridal expo."[93]

Global warming is threatening Great Lakes cultural traditions and ancient ways of life. Low water levels for the first time in 2007 resulted in cancellation of wild rice harvest by the Bad River Tribe in northern Wisconsin. "For us, it's not just a food crop—it's medicine," tribal game warden Matt O'Claire said. "What happens to the rice happens to us, and it's the same with the wolf or anything else."[94]

Since 2000, unseasonably warm winter temperatures have caused cancellation of the Plymouth, Michigan, Ice Festival (2002); collapse of the ice sculptures at the Saint Paul, Minnesota, Ice Carnival (2007); and relocation of the Madison, Wisconsin, Kites on Ice event to a part of Lake Monona with safer ice (2002). Sledding; skating on lakes, ponds and backyard rinks; skiing; ice-fishing and building snow forts may increasingly become the nostalgic memories of an older generation rather than the typical winter experience for children in much of the Great Lakes region. John J. Magnuson, a limnologist at the University of Wisconsin, says continued warming of Great Lakes winters could cost the region "a north temperate sense of place."[95]


The Great Lakes are already experiencing some of the impacts of global warming, including higher water temperatures and less ice cover in the winter.

PHOTO: USEPA

Winter isn't the only season that is changing. Lilacs used to decorate Midwest cemeteries on Memorial Day, but now typically bloom much earlier in May.[96] Crisp autumn days come later

than they used to, with warm summer weather lingering well into September. Summer weather is hotter—especially the nights—and heat waves are more common.[97]

The National Park Service has begun assessing the potential impacts of climate change on the national park units in the Great Lakes Basin. These include: Grand Portage National Monument (Minnesota); Apostle Islands National Lakeshore (Wisconsin); Isle Royale National Park, Keweenaw National Historical Park, Pictured Rocks National Lakeshore and Sleeping Bear Dunes National Lakeshore (Michigan); Indiana Dunes National Lakeshore (Indiana); and Perry's Victory and International Peace Memorial (Ohio). Three of these units, Apostle Islands, Sleeping Bear Dunes and Indiana Dunes National Lakeshores, attract a combined total of more than 3.5 million visitors annually.[98] "National parks may not be able to meet their mandate of protecting current biodiversity within park boundaries for mammals. Park wildlife, able to move northward or to higher elevation to avoid global warming impacts, may be forced out of the parks and into unprotected habitats."[99]

In a 2007 summary of potential impacts, the Park Service predicted that:

- global warming will create longer seasons for popular warm-weather activities such as swimming, camping, boating and kayaking and create wider beaches for visitors to enjoy, but that severe storms may increasingly affect campers, boaters and hikers;
- the winter recreational season will get progressively shorter as snow and ice decrease;
- the increasing frequency and intensity of severe storms could threaten historic structures such as lighthouses and farmsteads, as well as roads and trails, archeological sites and other park facilities;
- recreational fishing will change because of shifts in fish communities and drying of ephemeral wetlands on lake margins that serve as critical nursery habitat for species such as whitefish, with migratory birds and other wetland-dependent plants and wildlife also likely to be affected;
- forest composition in Apostle Islands will change from a northern hardwood/boreal mix to more southern species, and paper birch habitat may virtually disappear from the entire Great Lakes region;
- park facilities may be inadequate for new conditions, with fixed docks and boat ramps possibly becoming too high as lake levels decline, requiring public spending on new infrastructure;
- decreasing lake levels will make some areas of the lakes inaccessible to many watercraft;
- pest populations and invasive species could rapidly damage vegetation in parks, since insects and pathogens have shorter life spans than do most forest vegetation and can respond swiftly to global warming; and
- changes in habitat may cause rapid and "unprecedented shifts in mammalian species," threatening such populations as the Isle Royale moose herd.[100]

National Parks at Risk

PICTURED ROCKS NATIONAL LAKESHORE

The road leading to Pictured Rocks' Twelve Mile Beach has welcomed visitors through the swaying arches of a spectacular birch forest for generations. The white birches could be among the trees that vanish as climate warms. Moreover, shores could become cluttered with the shells of invasive zebra and quagga mussels.

APOSTLE ISLANDS NATIONAL LAKESHORE

White pines are an iconic tree of northern Great Lakes country. Before the 19th-century logging boom, these lofty giants filled much of the landscape of Michigan, Wisconsin and Minnesota. In recent decades, they have been given a safe haven in the national parks and lakeshores, but rising temperatures and frequent droughts may end their long legacy as sentinels on the shores of the Great Lakes.

INDIANA DUNES NATIONAL LAKESHORE

Historic and important wetlands, such as Cowles Bog at Indiana Dunes National Lakeshore, may shrink from evaporation and lowering lake levels (which also will affect nearby inland water tables that provide water to communities and industry), threatening these vital habitats and the wildlife they support.

SLEEPING BEAR DUNES

At Sleeping Bear Dunes, some treasured beaches may expand with dropping lake levels, but others may emerge as mud flats.

ISLE ROYALE NATIONAL PARK

For many visitors, the unparalleled experience of remote Isle Royale National Park includes hearing wolves call or seeing a moose—two species that interact in a delicate ecological balance. Unreliable winter ice conditions may prevent wolves from crossing from the mainland to replenish the population's genetic diversity. The loss of boreal forest habitat and increased stress from insects threatens to undermine survival of moose. The disappearance of one or both species would profoundly change the nature of Isle Royale.

PHOTO: Department of Environmental Quality

PHOTO: Healing Our Waters Coalition/Suzanne Ritchie

Recommendations for Action

PHOTO: National Wildlife Federation/Jordan Lubetkin

Swift national action to cut global warming pollution, hand-in-hand with comprehensive action to protect and restore the Great Lakes, is essential. Implementation of the Great Lakes Regional Collaboration Strategy and passage of the Great Lakes Water Resources Compact will revive the health of the Great Lakes and will help to buffer the impacts of global warming. Working together, international, federal, state, city and tribal entities, in cooperation with individuals, industries and business, can overcome the challenges of global warming. The following are recommendations for restoring and protecting the Great Lakes in a changing climate.

Fully fund Great Lakes restoration and protection

Helping the region's environment and economy respond to a changing climate requires Congress to fund restoration and protection programs fully. The Great Lakes Regional Collaboration's (GLRC) "Strategy to Restore and Protect the Great Lakes" outlined commonsense solutions. Restoring and protecting the Great Lakes will enhance their ability to adapt to changes caused by global warming. Federal Great Lakes programs direct funds to regional projects that implement these solutions in a way that responds directly to the unique problems facing the Great Lakes ecosystem.

Create an ecosystem restoration and adaptation fund

A permanent source of funding is needed for fully budgeting Great Lakes and other ecosystem restoration programs. Current congressional proposals for controlling global warming pollution create a new system of permits for major emitters of greenhouse gases. A portion of the revenue generated from auctioning these permits should be reserved for ecosystem restoration and adaptation. This strategy is one way to provide an unprecedented, permanent investment in protecting the Great Lakes and all ecosystems in the United States.

Pass the Great Lakes Compact

Climate change will reduce water supplies and increase water demand in the Great Lakes Basin. At the same time, other regions of the United States also will suffer from severe water shortages, perhaps increasing pressure to

divert Great Lakes water to drier regions. Federal laws are not strong enough to protect the Great Lakes from the threat of water withdrawals. The Great Lakes Compact addresses this threat by banning diversion of water outside the Great Lakes Basin, with limited exceptions, and requiring water conservation to protect the resource. The compact's focus on protecting water resources from harm ensures that as climate and environment change, the Great Lakes will be protected.

Reduce greenhouse gas and other emissions

All levels of government must pass legislation to curb global warming pollution in order to limit the magnitude of changes to the climate and to natural ecosystems. Annual reductions equal to at least 2 percent of current annual emissions are essential to meet an 80 percent reduction by the middle of this century, a level of reduction that climate scientists have deemed necessary to avoid the worst impacts of global warming. At the same time, efforts to reduce other air pollutants, such as mercury, must continue in order to protect families and the Great Lakes environment from acid rain, mercury-contaminated fish, unsightly haze and unhealthy air.

Promote green energy and green jobs

America can meet a growing part of its energy needs by taking advantage of the energy-saving appliances, equipment and building construction practices available today and by taking advantage of Midwest technical and manufacturing expertise. The nation can deploy more renewable-energy-generating facilities, such as those powered by solar, wind or geothermal energy sources. Technologies available today also can reduce motor-vehicle emissions, increase fuel economy and save consumers money at the gas pump. Investing in energy efficiency and new energy technologies not only helps cut greenhouse gas emissions but also creates a new generation of jobs.

Engage Canada

Significant emissions reductions from every nation will be necessary to avoid the worst impacts of global warming. The Great Lakes are a bi-national resource, and adaptation and mitigation measures need to be taken on both sides of the border. U.S. policymakers must work with our neighbors to the north, south and around the world to put in place meaningful and enforceable agreements for reducing greenhouse gases to safer levels even while working to achieve independence from carbon-based fuels, as well as promoting restoration and protection measures throughout the basin. This international partnership is critical to restoring and protecting the Great Lakes.

Assess global warming impacts on the Great Lakes

Federal, state, tribal and municipal agencies all need the best scientific information available in order to make good management decisions. A continually updated, thorough assessment of the climate changes facing the Great Lakes, drawing on the expertise of researchers, agencies, tribes, nongovernmental organizations and industry, will help decision-makers make better decisions. These assessments also should be used by the Great Lakes Regional Collaboration implementation teams to ensure that the comprehensive restoration plan initiates measures that will help the Great Lakes adapt to a changing climate.

Take individual action

Not every solution to climate change takes an act of Congress or a scientific breakthrough. Everyone can do things in their daily lives to help reduce pollution and global warming. When buying a new car, consumers can consider a hybrid or other high-mileage model. Buying Energy Star appliances will use less energy and save on electric bills. Simply driving less, turning off unneeded lights and recycling can make an enormous difference, especially when everyone pitches in.

Endnotes

[1] Sierra Legal (now Ecojustice), November 2006. "The Great Lakes Sewage Report Card." Available online at: http://www.ecojustice.ca/publications/reports/the-great-lakes-sewage-report-card/attachment.

[2] Natural Resources Defense Council. July 2006. "Testing the Waters: A Guide to Water Quality at Vacation Beaches." Available online at: http://www.nrdc.org/water/oceans/ttw/sumgreatlakes.pdf

[3] Ibid: Great Lakes Regional Collaboration, 2005. Pg. 47.

[4] Ibid: Great Lakes Regional Collaboration, 2005. Pg. 23

[5] Ibid: Great Lakes Regional Collaboration, 2005. Pg. 18.

[6] Ibid: Great Lakes Regional Collaboration, 2005. Pg. 53

[7] J.C. Austin, S. Anderson, P.N. Courant and R.E. Litan, 2007, "Healthy Waters, Strong Economy: The Benefits of Restoring the Great Lakes Ecosystem." The Brookings Institution, Metropolitan Policy Program. Washington, D.C.

[8] J. Austin et al. 2007: "Health Waters, Healthy Economy: The benefits of restoring the Great Lakes ecosystem." The Brookings Institution. Pg. 1.

[9] Ibid, Pp. 6-9.

[10] J. Austin et al. 2008: "Place-Specific Benefits of Great Lakes Restoration: A supplement to the 'Healthy Waters' Report." The Brookings Institution. Pg. 2

[11] J. Austin et al. 2007: "Health Waters, Healthy Economy: The benefits of restoring the Great Lakes ecosystem." The Brookings Institution. Pg. 10.

[12] D. J. Wuebbles and K. Hayhoe. 2004. Climate Change Projections for the United States Midwest. *Mitigation and Adaptation Strategies for Global Change*: Pp. 335–363.

[13] Natural Resource Canada 2006.

[14] G.W. Kling *et al.* 2003: "Confronting Climate Change in the Great Lakes Region: Impacts on Our Communities and Ecosystems." *The Union of Concerned Scientists and The Ecological Society of America.*

[15] Ibid: Wuebbles and Hayhoe, 2004.

[16] Ibid: Kling, *et al.* 2003.

[17] B.M. Lofgren *et al.* 2002: "Evaluation of potential impacts on Great Lakes water resources based on climate scenarios of two GCMs." *Journal of Great Lakes Research* 28(4). Pp. 537-554.

[18] Ibid: Wuebbles and Hayhoe, 2004.

[19] S.D. Solomon *et al.* 2007: "Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." *Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

[20] Ibid: Wuebbles and Hayhoe, 2004.

[21] "Global Warming Means More Snow for Great Lakes Region," Science Daily, November 6, 2003. Available at: http://www.sciencedaily.com/releases/2003/11/031106052121.htm.

[22] Joel Scheraga *et al.* 2003: "Climate Change and Water Quality in the Great Lakes Region." *Great Lakes Quality Board, International Joint Commission* (hereafter cited as IJC) at 14. Available at http://www.ijc.org/rel/pdf/climate_change_2003_part3.pdf.

[23] N. Hall and B. Stuntz. 2007: "Climate Change and Great Lakes Water Resources." *National Wildlife Federation*. Available at: http://online.nwf.org/site/DocServer/Climate_Change_and_Great_Lakes_Water_Resources_Report_FI.pdf?docID=2442

[24] M.L. Parry *et al.* 2007: "Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." *Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY. Chapter 14, p. 18.

[25] Brent Lofgren *et al.* 2002: "Evaluation of Potential Impacts on Great Lakes Water Resources Based on Climate Scenarios of Two GCMs," *Journal of Great Lakes Research,* 28(4): 537-554. Available at: http://www.glerl.noaa.gov/pubs/fulltext/2002/20020020.pdf. The other model considered in the paper is the United Kingdom Meteorological Office's Hadley Center model.

[26] U.S. EPA and Environment Canada. 2006: "Lake Erie Lakewide Management Plan Report." Available at : http://www.epa.gov/glnpo/lakeerie/2006update/index.html.

[27] J. Austin and S. Colman 2007: "Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: A positive ice-albedo feedback." GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L06604. Available at: http://www.agu.org/pubs/crossref/2007/2006GL029021.shtml

[28] Ibid: Kling, *et al.* 2003.

[29] J.T. Lehman. 2002: "Mixing Patterns and Plankton Biomass of the St. Lawrence Great Lakes Under Climate Change Scenarios," *Journal of Great Lakes Research*. 28(4): 583-596.

[30] Ibid: Lehman, 2002.

[31] T.F. Nalepa *et al.* 2006: "Continued disappearance of the benthic amphipod Diporeia in Lake Michigan: Is there evidence for food limitation?" *Canadian Journal of Fisheries and Aquatic Sciences* 63:872-890.

[32] Council of Great Lakes Governors Web site. Available at: http://www.cglg.org/projects/water/CompactImplementation.asp

[33] Wisconsin Department of Natural Resources, "Cladophora in Lake Michigan Fact Sheet." Available at: http://dnr.wi.gov/org/water/greatlakes/cladophora/cladophora_factsheet.pdf

[34] R.L. Whitman *et al.* 2003: "Occurrence of *Escerichia coli* and enterococci in *Cladophora* (Clorophyta) in nearshore water and beach sand of Lake Michigan." *Applied and Environmental Microbiology* 69(8): 4714-4719; "Cladophora Research and Management in the Great Lakes; Proceedings of a Workshop Held at the Great Lakes WATER Institute." University of Wisconsin-Milwaukee, Dec. 8, 2004. Available at: http://www.glwi.uwm.edu/research/aquaticecology/cladophora/Cladophora_Proceedings.pdf

[35] K. Hyde. 2007: "Type E Botulism at Sleeping Bear Dunes National Lakeshore." Presented at 5th Biennial State of Lake Michigan Conference, , Traverse City, MI. Available at: http://www.miseagrant.umich.edu/SOLM2007/images/presentations/invasives/Ken-Hyde.pdf; D. Blehert, 2007: "Avian Botulism." Presented at 2007 State of Lake Michigan Conference. Available at: http://www.miseagrant.umich.edu/SOLM2007/images/presentations/GLBA/Blehert-GLBA-10_4_07.pdf

[36] John Fauber and Tom Vandenbrook. "Global Warming May Take Great Lakes Gulp," Milwaukee *Journal-Sentinel*, June 14, 2000 Available at: http://www2.jsonline.com/news/state/jun00/lake14061300a.asp.

[37] Associated Press. "Climate Change Experts Predict Drop in Lake Erie Water Levels." July 24, 2006. Available at: http://www.climateark.org/shared/reader/welcome.aspx?linkid=58668.

[38] Ibid: IJC at executive summary, P. 4.

[39] Ibid, IJC at Chapter 3, p. 21.

[40] Janet Pelley. 2004: "POPs levels linked to climate fluctuations." Environmental Science & Technology Online.

[41] D. Swackhamer. *et al.* 2004: "Impacts of Atmospheric Pollution on Aquatic Systems." Issues in Ecology, Number 12Available at: http://epa.gov/owow/airdeposition/ESA_Air_Dep_Ecosystems.pdf

[42] Ibid: Field, et al. 2007.

[43] Ibid: Field, et al. 2007.

[44] Jerrry Zremski. "Warming Study Sees Problems for Great Lakes: Drop in Water Quality Tied to Lower Levels," *Buffalo News*, April 17, 2007. Available at: http://www.redorbit.com/news/display/?id=905525.

[45] National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory. 2007: "Aquatic Invaders and the Great Lakes: Simple Questions, Complex Answers." Available at: http://www.glerl.noaa.gov/pubs/brochures/invasive/AIS.pdf.

[46] M.E. Taylor, P.A. Gray and K. Schiefer. 2006: "Helping Canadians adapt to climate change in the Great Lakes coastal zone." *Great Lakes Geographer*, 13(1): 14-25.

[47] Ibid: Taylor, *et al.* 2006.

[48] Union of Concerned Scientists, "Confronting Climate Change in the Great Lakes Region, Technical Appendix, Wetlands." Available at: http://www.ucsusa.org/greatlakes/pdf/wetlands.pdf.

[49] U.S. EPA. 1995: "Ecological Impacts from Climate Change: An Economic Analysis of Freshwater Recreational Fishing." Available

at: http://nepis.epa.gov/EPA/html/Pubs/pubtitleOther.htm. Scroll down to document 220-R95-004.

[50] National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, "Great Lakes Ice Cover." Available at: http://www.glerl.noaa.gov/pubs/brochures/ice/icecover.html.

[51] C. Maag. "On Great Lakes, Winter is Served Straight Up," *New York Times*. February 19, 2006.

[52] B. Heath. "Warmer Climate Will Change Lakes: Some Say Global Warming Will Lower Lake Levels; Others Fear Devastated Crops," Detroit News, August 14, 2005. Available at: http://detnews.com/2005/project/0508/14/Z12-275412.htm.

[53] P. Glick. 2005: "The Waterfowler's Guide to Global Warming." National Wildlife Federation. Available at: http://www.nwf.org/globalwarming/pdfs/WaterfowlersGuideToGlobalWarming.pdf

[54] National Wildlife Federation, "Ducks and Global Warming." Available at: http://www.nwf.org/birdsandglobalwarming/ducks.cfm

[55] Minnesota Pollution Control Agency. 2008: "Global Climate Change and Its Impact on Minnesota," Available at: http://www.pca.state.mn.us/hot/globalwarming.html.

[56] U. S. Environmental Protection Agency, National Parks Service, and U.S. Fish and Wildlife Service. 2002: "Climate Change, Wildlife and Wild Lands: A Case Study; Great Lakes and Upper Midwest." Available at: http://www.epa.gov/climatechange/wycd/downloads/CS_glum.pdf .

[57] National Assessment Synthesis Team, U.S. Global Change Research Program. 2000: "Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Overview: Midwest." Available at: http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewmidwest.htm.

[58] J. Bloomfield. 2000: "The Potential Impacts of Global Warming on America's Forests." Available at: http://www.climatehotmap.org/impacts/forests.html

[59] B. Bradley. "Bug Off: Global Warming Increases Pest Growth," Northern Life.ca, August 8, 2006. Available at: http://www.northernlife.ca/News/Lifestyle/2006/08-09-06-bug.asp?NLStory=08-09-06-bug

[60] Lake Michigan Fisheries Team, Wisconsin Department of Natural Resources, Lake Michigan Management Reports, March 2007; Lake Michigan Fisheries Team, Wisconsin Department of Natural Resources, Lake Michigan Integrated Fisheries Management Plan, 2003- 2013, January 2004.

[61] T. Newcomb. 2008: "The Changing Character of Lake Huron's Fishery-Pandemonium or Promise?" Presented at The Great Lakes: An Ecosystem in Transition. East Lansing, Michigan. Available at: http://www.hydra.iwr.msu.edu/iwr/events/ANRWeek/2008/ChangingCharacterFishery.pdf

[62] J. Lindeberg and G. Albercook. 2004: "Climate Change and Great Lakes Shipping/Boating." Center for Environmental Policy, Economics and Science, Ann Arbor, Mich. Available at: http://www.geo.msu.edu/glra/PDF_files/Regional%20Summary/04F_WRES_F.boating.pdf.

[63] Ibid.

[64] Associated Press. "Great Lakes Waters' Drop: Shipping Industry Takes it On the Chin Every Inch That Waters Dip," July 3, 2006. Available at: http://www.climateark.org/shared/reader/welcome.aspx?linkid=57920.

[65] Grant Lafleche. "Global Warming Imperils Shipping on Great Lakes," St. Catherines Standard, December 13, 2000.

[66] NOAA News. "NOAA projects Lake Superior may hit record low levels this fall." August 16, 2007. Available at: http://www.noaanews.noaa.gov/stories2007/s2909.htm

[67] F.H. Quinn. 2002: "The Potential Impacts of Climate Change on Great Lakes Transportation." Presented at workshop hosted by Center for Climate Change and Environmental Forecasting, U.S. Department of Transportation, Available at: http://climate.volpe.dot.gov/workshop1002/quinn.pdf

[68] A. Minard. "Shrinking Lake Superior Also Heating Up." National Geographic News. August 3, 2007. Available at: http://news.nationalgeographic.com/news/2007/08/070803-shrinking-lake.html.

[69] U.S. Army Corps of Engineers, Great Lakes Update, 2007 Annual Summary, U.S. Army Corps of Engineers, Detroit District. 2008: "Great Lakes Update: 2007 Annual Summary." Available at: http://www.lre.usace.army.mil/_kd/Items/actions.cfm?action=Show&item_id=5753&destination=ShowItem

[70] J. Flesher. "Huge Lake Superior is Shrinking, Warming," Associated Press, August 7, 2007. Available at: http://www.msnbc.msn.com/id/20145325/.

[71] T. Nalepa. 2007: "The Continued Expansion of the Quagga Mussel Population in Lake Michigan." Presented at 5th Biennial State of Lake Michigan Conference, Traverse Bay, MI. Available at: http://www.miseagrant.umich.edu/SOLM2007/images/presentations/invasives/Thomas-Nalepa.pdf

[72] U.S. EPA. "Quagga Mussels Confirmed in Duluth – Superior Harbor by US EPA." U.S. EPA news release, Jan. 11, 2007. Available at: http://www.epa.gov/ord/newsreleases/newsrelease-011107.html

[73] U.S. Global Climate Change Research Program. 2003: "U.S. National Assessment of Climate Variability and Change, Regional Paper: Great Lakes." Available at: http://www.usgcrp.gov/usgcrp/nacc/education/greatlakes/greatlakes-edu-4.htm. Retrieved August 30, 2007

[74] Ibid.

[75] U.S. National Assessment of the Potential Consequences of Climate Variability and Change Educational Resources Regional Paper: Great Lakes. Available at: http://www.usgcrp.gov/usgcrp/nacc/education/greatlakes/greatlakes-edu-4.htm

[76] Ibid.

[77] M. Wander. "Is Climate Changing?" ACES News. University of Illinois College of Agricultural, Consumer and Environmental Sciences, February 18, 2005. Available at: http://www.aces.uiuc.edu/news/stories/news3045.html.

[78] Union of Concerned Scientists. 2006: "Great Lakes Communities and Ecosystems At Risk: Climate Change in Michigan: Climate Change Impacts: Agriculture." Available at: http://www.ucsusa.org/greatlakes/glregionmic_agr.html.

[79] G. Trowbridge. "Warming Saps Great Lakes: Water Levels Could Take a Big Drop as Earth Gets Hotter." Detroit News. April 7, 2007. Available at: http://www.climateark.org/shared/reader/welcome.aspx?linkid=72524.

[80] C. Guyette. "The Heat is On: What Global Warming Could Mean for Michigan," Metro Times. July 4, 2007. Available at: http://www.metrotimes.com/editorial/story.asp?id=10707.

[81] Union of Concerned Scientists. 2005: "Confronting Climate Change in the Great Lakes Region: New York." Available at: http://www.ucsusa.org/greatlakes/glregionnew_agr.html.

[82] D. Gahl. 2006: "Forecast For New York: Projected Global Warming Impacts and Next Steps." Environmental Advocates of New York, p. 11. Available at: http://www.eany.org/gw/ForecastForNewYork.pdf.

[83] U.S. Global Climate Change Research Program. 2003: "U.S. National Assessment of Climate Variability and Change, Regional Paper: Great Lakes." Available at: http://www.usgcrp.gov/usgcrp/nacc/education/greatlakes/greatlakes-edu-4.htm. Retrieved August 30, 2007

[84] Ibid

[85] K.Levine. "Cheesemakers Taste a Change in the Weather." National Public Radio. August 30, 2007. Available at: http://www.npr.org/templates/story/story.php?storyId=13981929

[86] U.S. Global Climate Change Research Program. 2003: "U.S. National Assessment of Climate Variability and Change, Regional Paper: Great Lakes." Available at: http://www.usgcrp.gov/usgcrp/nacc/education/greatlakes/greatlakes-edu-6.htm.

[87] Union of Concerned Scientists. 2005: "Confronting Climate Change in the Great Lakes Region: Minnesota." Available at: http://www.ucsusa.org/greatlakes/pdf/minnesota.pdf.

[88] R. Thomas. "Tourism industry deals with climate change: Snow didn't come in time." Businessnorth.com. March 19, 2007. Available at: http://

www.businessnorth.com/viewarticle.asp?articleid=1820.

[89] Michigan Environmental Council. 2007. Press Release. Available online at: http://www.mecprotects.org/pr10_10_07.htm

[90] K. Schneider. "Global Warming Melting Michigan's Economy." Michigan Land Use Institute. April 21, 2004. Available at: http://www.mlui.org/landwater/fullarticle.asp?fileid=16687.

[91] K. Alvord. "Businesses Feel the Heat: Lake Superior Warms Up, Part Three," Keewenaw Now. July 15, 2007. Available at: http://www.keweenawnow.com/news/clim_ch3_07_06/climate_ch3.htm.

[92] E. Shaw. "Global Warming Could Further Damage Michigan's Economy." Flint Journal. April 22, 2007. Available at: http://blog.mlive.com/michigan/2007/04/global_warming_could_further_d.html.

[93] Ibid

[94] C. Dally. "Bad River Wild Rice Harvest Cancelled," Daily Press (Ashland, Wisconsin). August 9, 2007. Available at: http://www.ashlandwi.com/placed/index.php?story_id=214427.

[95] J.J. Magnuson. "Sustaining Water Futures in a Changing Climate: A Wisconsin View." October 21, 2003, http://www.soils.wisc.edu/~ss606/2003%20Fall/Magnuson%20Slides%20as%20Handout%20(10-21-03).pdf.

[96] T. Lovejoy. 2007: "Climate Change: Prospects for Nature." The Heinz III Center for Science, Economics and the Environment. Pg.22. Available at: http://www.heinzctr.org/NEW_WEB/PDF/Climate_Change_Prospects_Lovejoy_Jul_2007.pdf

[97] Ibid: Kling, et al. 2003. Available at: http://www.ucsusa.org/assets/documents;global_warming/GL-exec-sum-Reference-Version.pdf

[98] National Park Service. "Supplemental Document 2: Summary of Park Statistics and Resources for Great Lakes Inventory and Monitoring Network Parks," Available at: http://www.nature.nps.gov/im/units/glkn/Phase%20III%20Final%2010_06/GLKN%20SD%202%20-%20Park%20summaries.pdf. Accessed August 2007; National Park Service. "Indiana Dunes National Lakeshore: Park Statistics." http://www.nps.gov/indu/parkmgmt/statistics.htm. Accessed August 2007.

[99] Natural Resources Stewardship and Science Directorate, National Park Service, U.S. Department of the Interior, "Climate Change and Impacts to Resources around the Great Lakes: Talking Points," NPS/NRSS—2007/001, August 2007. Pg. 8.

[100] Great Lakes Area, National Park Service. 2007: "Climate Change: Impacts of Midwest Warming: Dying Birch Trees, Minimal Snowpack, and Ice Free Lakes are Just Some Impacts of Global Warming." Available at: http://www.nps.gov/climatefriendlyparks/downloads/Publications/2007%20MWR%20Climate%20Change%20Site%20Bulletin%20-%20Great%20Lakes%20FINAL.pdf; U. S. Environmental Protection Agency, National Parks Service, and U.S. Fish and Wildlife Service. 2002: "Climate Change, Wildlife and Wild Lands: A Case Study; Great Lakes and Upper Midwest." Available at: http://www.epa.gov/climatechange/wycd/downloads/CS_glum.pdf .

PHOTO: Healing Our Waters Coalition/Doug Marshak


HEALTHY LAKES
HEALTHY LIVES
HEALTHYLAKES.ORG