Great Lakes RESTORATION

ADAPTING TO CLIMATE CHANGE: A PLANNING GUIDE FOR STATE COASTAL MANAGERS– A GREAT LAKES SUPPLEMENT

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Cover Image: A view of the Great Lakes from SeaWiFS satellite. 2000. Credit: NASA Visible Earth. Source: NOAA GLERL.

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Foreword

In a world where fresh surface water is increasingly in demand, the Great Lakes region contains some 20 percent of it. Recognizing the importance of the Great Lakes to our nation and the need for action, President Obama has made restoring the Great Lakes a national priority. Through this commitment to restoring the Great Lakes, $475 million was invested in the region in 2010, by way of the Great Lakes Restoration Initiative (GLRI). For more information on President's initiative and the action plan, go to http://www.greatlakesrestoration.us.

As one of 15 federal agencies collaborating with the U.S. Environmental Protection Agency to implement this effort, the National Oceanic and Atmospheric Administration (NOAA) was allocated $29.72 million. NOAA brings strong science, data products, partnerships and forecasting capabilities to help achieve restoration goals. NOAA is making significant contributions to the GLRI through several projects. By expanding and enhancing many well-established programs and by advancing the science in many areas that have been identified as critical to the success of the initiative, NOAA is adhering to the GLRI principles of accountability, action, and urgency.

With some of the funding from the GLRI, NOAA's Office of Ocean and Coastal Resource Management produced a Great Lakes supplement to its *Adapting to Climate Change: A Planning Guide for State Coastal Managers*, which was released in 2010. The purpose of the planning guide is to help U.S. state coastal managers develop and implement adaptation plans to reduce the impacts and consequences of climate change and climate variability along their coasts. The planning guide includes science-based information on climate change and steps for setting up a planning process, assessing vulnerability, devising a strategy, and implementing the plan. It is based on needs assessments and a wide variety of resources specific to climate change, sustainability, resilience, general hazard mitigation, and natural resource management.

This Great Lakes supplemental report is intended to be used as a companion to the 2010 planning guide. It provides more specificity on climate trends and potential climate change impacts and consequences affecting the Great Lakes region and includes numerous case examples of adaptation actions already being taken at the regional, state, and local level. The supplement also refers readers back to sections of the planning guide for more detailed information about the adaptation planning process, including adaptation measures that may be used to reduce the impacts of climate change in the region. The planning guide and supplement are just two of the many products and services that NOAA is offering to help the nation prepare for and address the impacts of climate change.

CHAPTER 1: INTRODUCTION

The Earth's atmosphere is warming, and nearly all communities around the Great Lakes will need to adapt to changes in regional climate over the next century. These changes include warming air temperatures; shifts in the timing, frequency, and severity of precipitation events; declining lake levels; and higher water temperatures and reductions in lake ice cover. Changes to regional climate pose increased risks to the water resources, built environment and infrastructure, ecosystems, and recreation and tourism sectors that already face other pressures such as invasive species, urban development, and economic competition.

While many governments, and other public and private entities, around the world are taking steps to reduce greenhouse gas emissions, the current pace of mitigation efforts will not reduce emissions levels in the atmosphere quickly enough to avoid projected impacts for at least the next few decades. Efforts to prepare for these and longer-term impacts are needed, and in many towns and cities around the region, efforts have begun. Climate variability and change exacerbate many existing vulnerabilities and add to the complexity of resource management, capital investment, and community planning. Many Great Lakes states, communities, and organizations recognizing this fact have undertaken steps to incorporate climate change and associated impacts into planning and policy initiatives.

Batchawana Bay, Ontario, Lake Superior. 2010. Credit: J. Cavaletto. Source: NOAA GLERL.

This supplemental report for the Great Lakes region is intended to complement *Adapting to Climate Change: A Planning Guide for State Coastal Managers*, which the National Oceanic and Atmospheric Administration (NOAA) Office of Ocean and Coastal Resources released in 2010. The planning guide includes science-based information on climate change and steps to help coastal managers set up a planning process, assess vulnerability, devise a strategy, and implement a plan to minimize climate change impacts on their coasts. The planning guide also provides an extensive list of resources to help coastal managers throughout the planning and implementation process. This guide is described in more detail in Chapter 4.

This Great Lakes supplemental report provides updated data and information on climate phenomena and the potential climate change impacts and consequences for Great Lakes coastal areas. It highlights case examples of adaptive actions taking place in the Great Lakes region today, many of which are still in the planning and policy development stages, and it is designed to aid policymakers, coastal managers, and planning professionals as they begin to address the impacts of climate change. Throughout the Great Lakes supplement, readers are referred back to sections of the planning guide for more detailed information about the adaptation planning process, including adaptation measures that may be used to reduce the impacts of climate change in the region.

METHODOLOGY

Information in this report is based on interviews and a review of climate change literature for the Great Lakes region. Climate change phenomena, impacts, and consequence data were collected from a variety of climate change assessments, scientific literature, and reports by non-governmental organizations. This compilation is not a formal literature review of all the resources and scientific information available but rather a summary of the most current and relevant research and issues targeted to coastal and resource managers and planners.

State coastal managers completed structured interviews to provide valuable insights into the local impacts of climate change and potential case examples. These interview questions are included in the Appendix.

Along with the literature review and interviews with state coastal managers, a list of potential case examples of state, regional, and local organizations taking action to plan for and begin to adapt to the impacts of climate change in the Great Lakes region was collected. The list of examples was gathered from the following sources:

- Interviews with state coastal managers;
- Outreach to state Sea Grant climate change researchers;
- National and international programs like the Clinton Climate Initiative, U.S. Conference of Mayors, Center for Clean Air Policy Urban Adaptation Leaders Initiative, EcoAdapt, and ICLEI's Climate Resilient Communities;
- Outreach to ICLEI regional managers for the Midwest and Northeast;
- Discussions with university faculty working on climate change adaptation issues at the Great Lakes Regional Integrated Sciences and Assessments Center, the Cities Climate Initiative at University of Michigan, and the University of Wisconsin at Milwaukee;
- Questions incorporated into the NOAA Great Lakes Climate Needs Survey conducted by Old Woman Creek National Estuarine Research Reserve; and
- Independent research and assessments.

While there are hundreds of excellent examples of coastal management, ecosystem restoration, conservation, and stormwater management in the region, the case examples in this report specifically address responses to changing climatic conditions to build adaptive capacity or resilience for related systems.

Definitions of Key Terms

The following definitions are from the Intergovernmental Panel on Climate Change Fourth Assessment Report and will be used in this guide (IPCC, 2007). While this guide focuses on adaptation, it is important to understand the role of mitigation in addressing climate change and, ultimately, what it means for adaptation.

- **Adaptation**—Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
- **Mitigation**—An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

STRUCTURE OF REPORT

The Great Lakes Supplement provides information to aid policymakers and planning professionals as they begin to address the impacts of climate change. The report includes the following chapters:

- **Chapter 2: Great Lakes Climate and Future Climate Change** describes key climate change phenomena for the entire Great Lakes region, including data and information for temperature, precipitation and extreme events, lake level change, and water temperature and ice coverage.
- **Chapter 3: Great Lakes Climate Change Impacts and Consequences** offers an overview of how climate change phenomena will impact the water resources, the built environment and infrastructure, ecosystems, and recreation and tourism sectors and includes case examples of government agencies and organizations planning for and taking action to adapt to the future impacts of climate change.
- **Chapter 4: Climate Change Adaptation Planning** describes the report *Adapting to Climate Change: A Planning Guide for State Coastal Managers* and a series of NOAA training options available to professionals in the Great Lakes region. The chapter also includes examples of Great Lakes state, regional, and local government adaptation planning efforts.
- **Appendix: Interview Questions for State Coastal Managers** lists the interview questions for state coastal managers.

Lake Huron. 2001. Credit: M. McCormick. Source: NOAA GLERL.

Case examples are highlighted throughout the **Great Lakes Climate Change Impacts and Consequences** and **Climate Change Adaptation Planning** chapters with black boxes. A map highlighting the case examples is located on pp. 4-5.

Along with the case examples, the report draws attention to historic events or conditions in the region that may become more frequent as a result of climate change. These are displayed in boxes titled “Looking to the Past.”

Figure 1: Great Lakes Climate Change Adaptation Case Examples Map

The map highlights case examples of state, regional, and local organizations taking action to plan for and begin to adapt to the impacts of climate change in the Great Lakes region. These actions confront a range of climate change impacts across several sectors: water resources, the built environment and infrastructure, and ecosystems. Although individual case examples may cross multiple sectors, the map depicts each case example in the category that best represents the intended focus of the case example. Case examples that address multiple sectors and focus on plan development or technical assistance are included in the planning category. Case examples are highlighted throughout the Great Lakes Climate Change Impacts and Consequences and Climate Change Adaptation Planning chapters on the pages listed below.

Climate Change Adaptation Case Example Types

- **BE** Built Environment and Infrastructure
- **ES** Ecosystems
- **P** Planning
- **WR** Water Resources

A view of the Great Lakes from SeaWiFS satellite. 2000. Credit: NASA Visible Earth. Source: NOAA GLERL.

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CHAPTER 2: GREAT LAKES CLIMATE AND FUTURE CLIMATE CHANGE

Climate in the Great Lakes basin is influenced by three primary factors: its location within the middle of North America, the lakes themselves, and air masses from other regions (Canada & United States, 1995). The Great Lakes' central position in North America exposes the region to alternating flows of warm, moist air from the Gulf of Mexico and cold, dry air from the Arctic. Since the lakes gain and lose heat more slowly than the surrounding land, the water bodies moderate air temperatures near the lakes. The lakes also create micro-climates in the region, particularly on the downwind side of the lakes where portions of Michigan, New York, and Ontario remain warmer than other similar mid-latitude regions. The Great Lakes are probably best known for lake-effect snow, where cold, Arctic air masses move across the lakes picking up heat and moisture and depositing it in extreme snowfall events on the downwind (lee) side of the lake.

Great Lakes basin map. Source: NOAA GLERL.

OBSERVED CLIMATIC TRENDS

Regional climate can vary significantly from year to year, making it difficult to observe long-term trends. For instance, historic records for the last one hundred years show that annual temperatures can fluctuate by as much as 5°F from the long-term average for a particular year (Kling et al., 2003). Similarly, observed records for the last century demonstrate that seasonal precipitation can differ by over 40% from the long-term average during a given year (Kling et al., 2003). While annual variability makes it difficult to detect long-term trends, changes in regional climate can be observed by reviewing historic data for temperature, precipitation and extreme events, lake levels, and water temperature and ice coverage. The following table summarizes some information on observed changes to the climate for the Great Lakes region during the last century.

Table 1: Observed Changes to the Climate for the Great Lakes Region

Temperature
• Annual temperatures between 1970 and 2000 increased more than 0.4°F per decade for the Midwest, with winter temperatures rising 0.9°F per decade (Kling et al., 2003; Hayhoe et al., 2009). From 1970 to 2002, annual temperatures increased more than 0.5°F per decade in the Northeast, with winter temperatures rising 1.3°F per decade (Northeast Climate Impacts Assessment & the Union of Concerned Scientists [NECIA], 2006). • The past two decades include the hottest months in recorded history for the Great Lakes region (Kling et al., 2003). • The last spring freeze is now occurring one week earlier than in 1900 for the Great Lakes region (Kling et al., 2003).
Precipitation and Extreme Events
• The Midwest observed an increase in precipitation across all seasons of approximately 10% since 1900 (Minnesota Pollution Control Agency, 2010). The Northeast witnessed an increase of between 5%-10% in annual average precipitation since 1900 (NECIA, 2006). • The frequency of heavy rain events (defined as occurring once per year during the past century) doubled since the early 1900s across the Midwest and Northeast (Kunkel et al., 1999). • Compared to the long-term average, the frequency of 24-hour and 7-day intense rainfall events has been high during the last five decades for the Great Lakes region (Kling et al., 2003). • Between 1900 and 1990, the number of strong cyclones increased over the Great Lakes region, both annually and during the cold season. Strong cyclones more than doubled during November and December (Karl et al., 2008; Angel & Isard, 1998). • Since 1951, there has been an upward trend in snowfall along the southern and eastern shores of the Great Lakes (Burnett et al., 2003).
Lake Levels
• Great Lakes water levels have been highly variable with no clear trend towards lower water levels from 1860 to 2000 (Lofgren et al., 2002). • The Great Lakes experienced three decades of high water levels until the 1990s (Sousounis et al., 2000). • Since 1997 water levels on Lakes Michigan and Huron have fallen approximately 3.5 ft (Sellinger, 2008). • Between 1997 and 2000, the Great Lakes experienced a severe decline in lake levels. This episode is the most severe three-year drop on record for Lake Erie and the second most severe for Lakes Michigan, Huron, and Lake Superior (Assel et al., 2004). • The Great Lakes exhibited changes in the seasonal timing of water levels from the 1960s to 1998, with seasonal rises and falls of Lakes Ontario and Erie occurring one month earlier and maximum water level in Lake Superior occurring earlier (Lenters, 2001).
Water Temperature and Ice Cover
• Nearshore water temperatures increased around the eastern Great Lakes (McCormick & Fahnenstiel, 1999). • Summer surface-water temperature has increased by 4.5°F (2.5°C) since 1980 and by 6.3°F (3.5°C) since 1906 on Lake Superior, in excess of increases in air temperatures from 1979-2006 (Austin & Colman, 2007). • During the last four decades, extremes in annual average ice coverage have ranged from only along the perimeter of the Great Lakes to ice coverage of over 90%. The majority of the mildest winters with the lowest average ice cover occurred between 1997 and 2006 (Assel et al., 2003; Assel, 2005; Karl et al., 2008). • Since the early 1970s, the maximum amount of ice forming on the Great Lakes declined by at least 10% on each lake (Canada & U.S., 2009). • Surface wind speeds increased 5% per decade since 1985 on Lake Superior (Desai et al., 2009).

PROJECTIONS OF FUTURE CLIMATE

Atmosphere ocean general circulation models (AOGCMs) simulate the physical processes in the atmosphere, ocean, and land surface, and scientists use AOGCMs to understand the response of the global climate system to rising greenhouse gas concentrations. The models produce grid-based information including temperature, precipitation, humidity, and other climate variables at different time scales.

The global models, however, produce data that are not precise at regional or local scales. To support this need, researchers use statistical downscaling techniques to transform global climate model output into higher resolution projections that can be used to understand the impacts of climate change at the regional or local level. Downscaling often applies regionally specific historic data to calibrate the models, correcting climate variables like precipitation for factors such as topography.

This report describes climate change phenomena data from both downscaled models, where available, and AOGCMs to frame the discussion about climate change impacts and case examples. It does not evaluate the methods used to create downscaled data or the quality of the projections themselves. Rather, the climate change information described in this report illustrates the broad trends of temperature, precipitation and extreme events, lake levels, and water temperature and ice coverage to help decision-makers and planners understand the range of possibilities in the future. The primary sources of downscaled model results used in the Great Lakes supplement come from an assessment of climate change impacts on Chicago and the upper Midwest (Hayhoe et al., 2010a), the Midwest (Hayhoe et al., 2009), and the Northeast (NECIA, 2006).

Future Scenarios

The climate change models use Intergovernmental Panel on Climate Change (IPCC) scenarios that explore future development and greenhouse gas emissions. The scenarios are grouped into families according to a similar storyline. The IPCC defined four narrative storylines, A1, A2, B1, and B2, that describe the factors that drive greenhouse gas emissions. These factors include population growth, technological dispersion, energy sources, ecological factors, and economic growth (Nakićenović et al., 2000).

In particular, the storylines combine economic growth and environmental values to understand future emissions, and they are summarized as follows:

- **A1**: rapid economic growth, global population peaks mid-century and declines after, and rapid introduction of new technology
- **A2**: heterogeneous world with continuously increasing population and regionally-oriented economic growth that is slower than other storylines
- **B1**: global population peaks mid-century and declines after (same as A1), shift in economic structure to service- and information-based economy, introduction of more efficient technologies
- **B2**: emphasis on local solutions to economic, social, and environmental sustainability, increasing population but less than A2, intermediate economic development

Typically, more than one scenario storyline is used to capture the range of future greenhouse gas emissions and uncertainty in the assumptions about population growth, economic development, and technological deployment.

Uncertainty and Likelihood of Outcomes

The Great Lakes supplement uses common language to convey uncertainty about the range of possible outcomes and the likelihood of climate change impacts. The report uses the term “very likely” to describe an outcome that has at least a 90% chance of occurring and “likely” to describe an outcome that has at least a 66% chance of occurring. These expressions of likelihood are drawn from the work of the U.S. Global Change Research Program’s *Global Climate Change Impacts in the United States* assessment (Karl et al., 2009).

TEMPERATURE

Key Findings

- Annual temperatures in the Great Lakes region are expected to increase across all seasons but will vary by region and time period.
- *Regional variation*: Winter warming is expected to be largest in the northern portion of the region, while spring, summer, and fall warming are projected to be largest in the southern portion of the region.
- *Temporal variation*: Greater temperature changes during the winter (December, January, February) are anticipated in the early 21st century. By mid-century, temperatures are expected to increase more during the spring (March, April, May) and summer (June, July, August).

Certainty

- The occurrence of warmer air temperatures is very likely.

Associated Impacts

- Increased heat waves, exacerbated drought, more invasive species, shifts in species range, changes in timing of ecological events, reduced lake ice cover, earlier snow melt

Climate change will increase average temperatures across the Great Lakes region. By the end of the century, it is expected that higher emissions scenarios will result in greater annual and seasonal temperature increases as compared to lower emissions scenarios.

By 2040, average annual temperatures are projected to increase 2.6°F for lower and higher emissions scenarios in the Midwest and between 2.4°F (lower) and 2.6°F (higher) annually for the Northeast (Hayhoe et al., 2009; NECIA, 2006). By 2040, average winter (December, January, and February) temperatures are projected to increase more than summer temperatures, especially in the northern portions of the region (Hayhoe et al., 2009; Hayhoe et al., 2010a; Frumhoff et al., 2007).

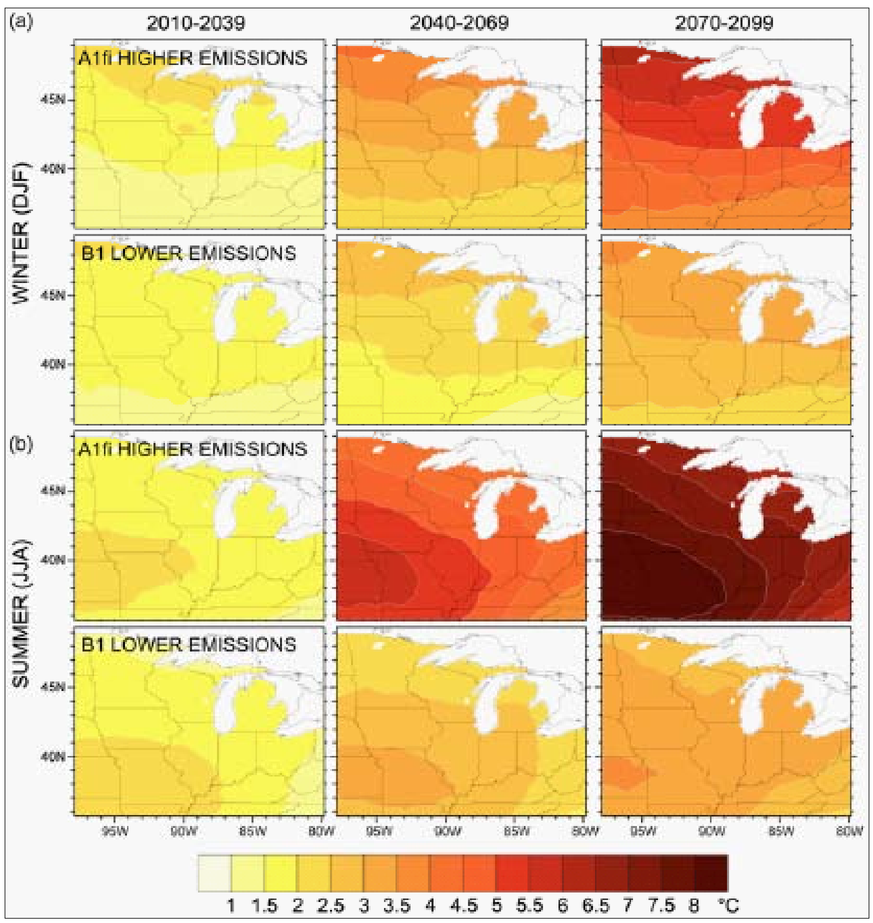

Figure 2: Projected increases in summer and winter average temperatures for a higher emissions scenario and a lower emissions scenario relative to the 1961-1990 average for the Midwest. Source: Hayhoe et al., 2010a.

By the end of the century, the average annual temperature in the Midwest is projected to increase 4.9°F to 5.1°F for a lower emissions scenario and 9.7°F to 10.3°F for a higher emissions scenario. For the higher emissions scenarios, average temperatures are expected to rise 7.6°F to 10.2°F in winter and 12.5°F to 14°F in summer (Hayhoe et al., 2009).

For the Northeast, the average annual temperature is expected to increase 5°F for a lower emissions scenario and 9.5°F for a higher emissions scenario by the end of the century. The winter season is projected to warm on average 5.8°F for a lower emissions scenario and 9.8° for a higher emissions scenario. Average summer temperatures are anticipated to rise 5.1°F for a lower emissions scenario and 10.6°F for a higher emissions scenario (NECIA, 2006).

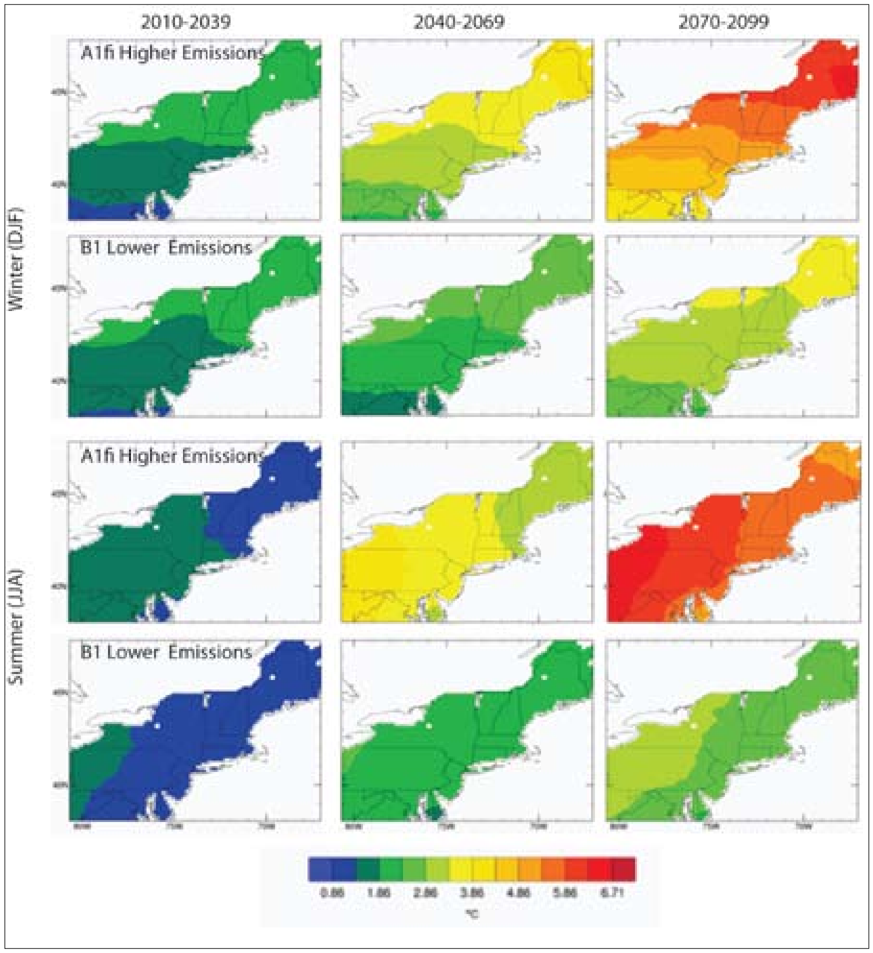

Figure 3: Projected increases in summer and winter average temperatures for a higher emissions scenario and a lower emissions scenario relative to the 1961-1990 average for the Northeast. Source: Hayhoe et al., 2008.

These long-term temperature increases will be experienced along with short-term variation (daily, annual, and multi-year) in temperature related to Earth system changes such as El Niño, La Niña, or volcanic eruptions. As a result, temperatures for a single day or year may be higher or lower than the long-term average (NASA, 2011).

PRECIPITATION AND EXTREME EVENTS

Key Findings

- Climate change is expected to increase annual precipitation slightly across the Great Lakes region.
- Relatively large increases in winter and spring precipitation are projected by the end of the century, with large decreases for summer months.
- The frequency of heavy rainfall events is expected to continue increasing (both 24-hour and 7-day) with longer dry spells in between.
- Fewer snow-cover days and less lake-effect snow are projected in the future.

Certainty

- Winter and spring precipitation, heavy rainfall events, and cold-season storms will likely increase. In the short-term, lake-effect snow is likely to increase, but over the long-term, lake-effect snow is likely to decline.

Associated impacts

- Increased flooding, changes to erosion rates, elevated non-point source pollution, exacerbated drought, mobilization of persistent legacy chemicals

An increase in summer and winter precipitation has been observed in the region over the last several decades with an increase in the frequency of heavy rain events, the number of strong cyclones over the region, and lake-effect snow (Midwest Regional Climate Center, 2011; Kling et al., 2003; Kunkel et al., 1999; Karl et al., 2008; Angel & Isard, 1998; and Burnett et al., 2003).

Changes to total precipitation are more difficult to project than changes in temperature, with a higher level of confidence for winter and spring than summer and fall. During the winter, precipitation is estimated to rise across the region by as much as 50% for the higher emissions scenario by century's end. During the summer, the western portion of the Great Lakes region

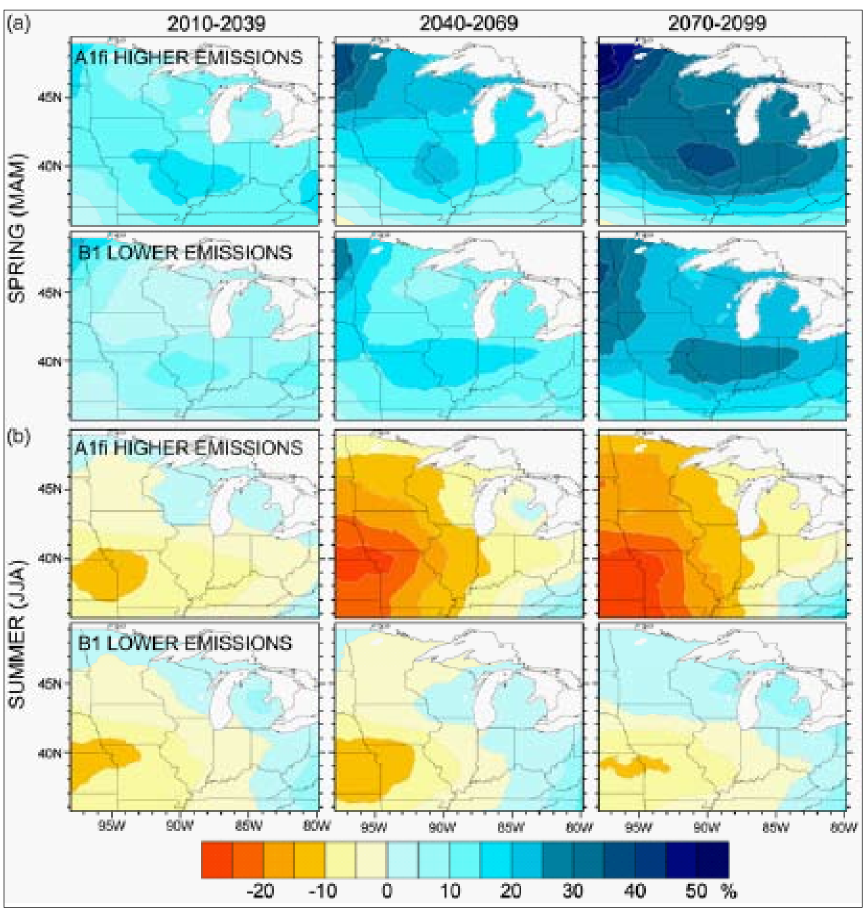

Figure 4: Projected change in the average precipitation for a higher emissions scenario and a lower emissions scenario relative to the 1961-1990 average for the Midwest. Source: Hayhoe et al., 2010a.

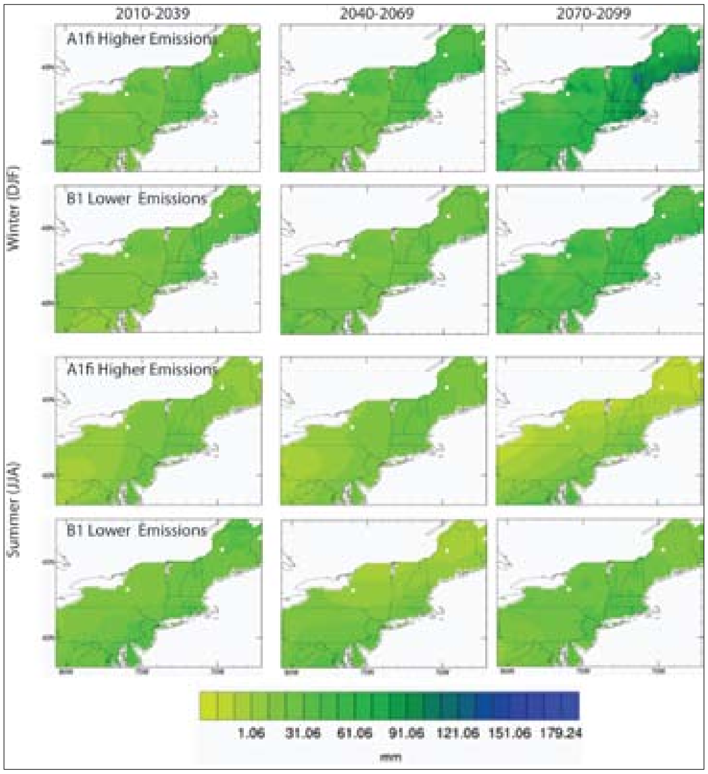

Figure 5: Projected change in the average precipitation for a higher emissions scenario and a lower emissions scenario relative to the 1961-1990 average for the Northeast. Source: Hayhoe et al., 2008.

is projected to receive between 15% and 25% less precipitation by the end of the century than historic averages for a higher emissions scenario (Hayhoe et al., 2010a).

Although more precipitation is expected during the winter months, warmer temperatures will result in more precipitation falling as rain instead of snow. By the end of the century, most states in Northeast may lose 4 to 8 snow-cover days for a lower emissions scenario and between 10 and 15 for a higher emissions scenario (NECIA, 2006; Frumhoff et al., 2007).

By the end of the century, lake-effect snow will likely decline resulting in more lake-effect rain. Warmer air temperatures during the winter are projected to reduce the suitable conditions for lake-effect snow between 50% and 90% by 2100 (Kunkel et al., 2002).

In the Great Lakes region, the amount of rain falling in the heaviest downpours increased during the last several decades and the trend is expected to continue in the future. Similarly, the frequency of heavy rainfall events is expected to continue increasing (both 24-hour and 7-day) with longer dry spells in between. In Cleveland, Ohio, for instance, the annual maximum precipitation for the 24-hour and 7-day events is projected to rise approximately 25% to 33% by the end of the century. The annual maximum precipitation for the 24-hour event in Milwaukee, Wisconsin, is expected to rise approximately 33% to 52% by the end of the century (Hayhoe et al., 2009).

Projections for the Chicago, Illinois, area also suggest an increase in the wettest days of the year. By the end of the century, the frequency of very wet days (defined as the precipitation threshold corresponding to the wettest 5% of days during the late 20th century) is estimated to increase from 18.3 days to between 22.6 and 23.2 days per year. At the same time, extremely wet days, defined as those with precipitation exceeding 4 inches per day, are likely to increase from 1.5 days to between 1.9 and 2.5 days per year (Vavrus & Van Dorn, 2010).

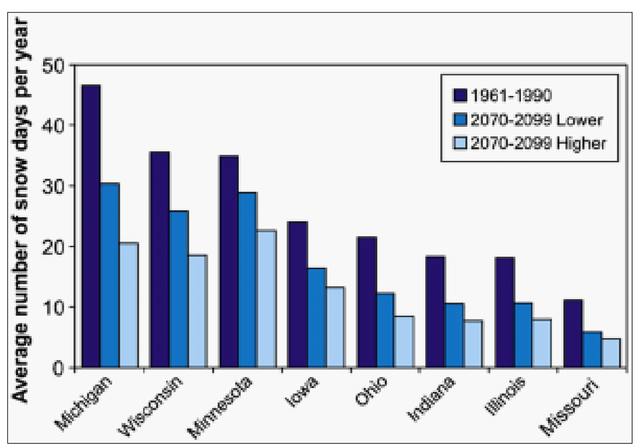

Figure 6: Projected change in the average number of snow days per year for a higher emissions scenario and a lower emissions scenario relative to the 1961-1990 average for the Midwest. Source: Hayhoe et al., 2010a.

LAKE LEVELS

Key Findings

- Warmer air and water temperatures along with reduced snowpack and shorter duration of ice cover are likely to result in greater evaporation and overall lower lake levels.
- The frequency and duration of low water levels could increase, falling below historic low water levels.
- Water level change will not be equal among all lakes with Lake Superior expected to change the least and Lakes Michigan and Huron the most.
- Considerable range in the change in lake levels is due to differences in precipitation patterns and evapotranspiration.

Certainty

- Lake levels will likely decline.

Associated Impacts

- Water supply declines, aquatic habitat loss, changes to erosion rates, more invasive species with a shift in their range

By the end of the century, average Great Lakes water levels will likely decline. In the most comprehensive examination of changes to water levels to date, 23 Global Circulation Models were used to examine the response of Great Lakes water levels to future climate scenarios. Of the more than 600 climate scenarios tested, average water levels on Lake Superior are expected to change the least, while lakes Huron and Michigan are projected to decline the most (Angel & Kunkel, 2010).

While the full range of potential lake level changes in this study was broad, including the possibility of lake level increases, over 75% of all the model simulations showed steady or declining lake levels for a higher emissions scenario for all of the Great Lakes. Twenty-five percent of the models resulted in a decline of approximately three-quarters of a foot on Lake Superior, over one and three-quarters feet on Lake Erie, and approximately two and a quarter feet on Lakes Huron, Michigan, and Ontario. For a lower emissions scenario, lake levels are projected to change very little from the historic average (Angel & Kunkel, 2010).

Although the emissions scenarios all showed consistent warming, model simulations resulted in precipitation patterns that included both wetter and drier conditions. The model simulations were also influenced by factors, including runoff, the rate of evaporation and evapotranspiration, and basin soil moisture (Angel & Kunkel, 2010).

Table 2: Projected Decline in Average Lake Levels in 2080 for a Higher Emissions Scenario Relative to the 1970-1999 Average for the Great Lakes (in feet)

Percentile	Erie	Huron & Michigan	Ontario	Superior
25th	-1.83	-2.44	-2.28	-0.74
50th (Average)	-1.03	-1.32	-1.25	-0.39
75th	at least -0.42	-0.42	at least -0.42	~0
Full range	-4.21 to +1.96	-5.68 to +2.86	-5.3 to +2.57	-1.86 to +1.12

Source: Angel & Kunkel, 2010.

Along with changes to average Great Lakes water levels in general, water levels are also projected to vary by season and over longer multi-year periods due to climate-related factors. Inter-annual fluctuations reflect the interaction between water losses from evaporation and evapotranspiration and water gains from precipitation. Typically, lake levels are at their lowest during the winter, rising in spring as snowmelt increases water flow into the lakes. The Great Lakes reach their annual maximum levels between the summer and early fall depending on the lake, and then decline into the winter (Mortsch et al., 2006).

Climate change could alter this seasonal progression. Higher temperatures and more precipitation during the winter are expected to result in more runoff into the lakes and higher lake water levels. Earlier snowmelt due to higher temperatures is likely to produce higher water levels during the spring. The shift in timing for precipitation and runoff, coupled with more summer and autumn evaporation and evapotranspiration, and less summer precipitation, is projected to lead to lower maximum summer water levels and an earlier decline in autumn water levels (Mortsch et al., 2006).

Manitowoc, Wisconsin, Lake Michigan. Credit: Phil Moy. Source: NOAA GLERL.


Put-in-Bay, Ohio, Lake Erie. Credit: Gary Garnet. Source: NOAA GLERL.

WATER TEMPERATURE AND ICE COVER

Key Findings

- Declining winter ice coverage will enable water temperatures to rise faster than air temperatures.
- All lakes will experience increased water temperatures and reductions in the extent and duration of ice cover.
- Warmer water temperatures will lead to a longer period of lake stratification.
- Higher surface water temperatures will increase wind speeds across the lake surface.

Certainty

- The occurrence of warmer water temperatures and decreased ice cover duration and extent is very likely.

Associated Impacts

- Shifts in species range, changes in the timing of ecological events, more invasive species, elevated risk of hypoxia, increased algal blooms

Ice cover on the Great Lakes is directly related to air temperature and the number and intensity of days below freezing. Since the early 1970s, the maximum amount of ice forming on the Great Lakes declined by at least 10% on each lake (Canada & U.S., 2009), and since 1963, the majority of the mildest winters with the lowest seasonal ice coverage occurred between 1997 and 2006 (Assel, 2005). Lake ice cover reduces the ability of a lake to absorb shortwave radiation that warms surface water temperatures. As lake ice cover declines, more radiation is absorbed by the lake, and surface water temperatures increase. Over the last several decades, Great Lakes water temperatures rose, often more quickly than air temperatures, as a result of declining ice coverage (Austin & Colman, 2007; Assel et al., 2003; Assel, 2005; Karl et al., 2008).

Based on climate change projections, the duration and extent of ice cover is expected to decrease in the future. For Lakes Superior and Erie, historic ice duration, the period of time with ice on the lake, from 1950-1995 ranged from 77 to 115 days. By 2030, two climate models project that this range will be reduced by 12 to 47 days for Lakes Superior and Erie. By the end of the century, this period of ice duration is projected to decline between 37 and 81 days—Lake Erie will have ice-free winters 96% of the time, while portions of Lake Superior will have ice-free winters 45% of the time (Lofgren et al., 2002).

As air temperatures increase in the winter and spring and ice cover declines earlier in the year, water temperatures begin to rise. When surface water temperatures reach approximately 39°F (4°C), a barrier forms between the warmer surface layer and the lower cooler layers and remains until water temperatures drop again in the fall (McCormick & Fahnenstiel, 1999). During this period of stratification, oxygen from the air is unable to circulate below the barrier to lower levels in the lake.

Climate change is expected to bring warmer air temperatures in the winter and spring months, resulting in an earlier loss of lake ice cover and increasing lake water temperatures. Lake Erie, the warmest of the lakes, is expected to have the smallest change in maximum summer surface water temperature, increasing 4.3°F for a lower emissions scenario and 5.9°F for a higher emissions scenario. Maximum summer surface water temperatures on Lake Superior, the coolest of the lakes, are projected to see the greatest increase, rising 8.3°F for a lower emissions scenario and 12.1°F for a higher emissions scenario (Trumpickas et al., 2009).

Table 3: Projected Increase in Maximum Summer Water Temperature and Change in Expected Days During Which Surface Water Temperatures Reach 50°F in the Spring and Fall for a Higher and a Lower Emissions Scenario Relative to the 1970-2000 Average for All Great Lakes

Scenario and Time Period		Maximum Summer Temperature (°F)				Change in Days Expected When the Surface Water Temperature Will Reach 50°F in Spring and Fall			
		Erie	*Huron & Michigan*	*Ontario*	*Superior*	*Erie*	*Huron & Michigan*	*Ontario*	*Superior*
Baseline	1970 – 2000	73.9	67.5	70.9	59.2	0, (historic ave. duration above 50°F is 184 days)	0, (historic ave. duration above 50°F is 134 days)	0, (historic ave. duration above 50°F is 149 days)	0, (historic ave. duration above 50°F is 85 days)
B2	2011–2040	75.2	69.6	73.2	62.8	18	19	19	29
	2041–2070	76.8	70.9	74.8	64.8	27	30	36	42
	2071–2100	78.1	72.1	76.6	67.5	42	45	54	62
A2	2011–2040	75.4	69.8	73.4	62.6	18	16	17	25
	2041–2070	76.5	71.4	75.4	66.0	36	37	44	52
	2071–2100	79.9	74.5	79.5	71.2	61	62	77	90

Source: Trumpickas et al., 2009.

These rising surface water temperatures translate into an increase in the summer stratified season, which is consistent with trends since the early 20th century (Trumpickas et al., 2009; McCormick & Fahnenstiel, 1999; Austin & Colman, 2007). By century's end, the maximum potential duration of the summer stratified season for Lake Erie is projected to increase 42 days for a lower emissions scenario and 62 days for a higher emissions scenario from a historic average of 184 days (Trumpickas et al., 2009). By the end of the century, the maximum duration of the summer stratified season on Lake Superior is expected to increase 62 days for a lower emissions scenario and 89 days for a higher emissions scenario from a historic average of 85 days (Trumpickas et al., 2009).

Temperatures for water layers below the surface, the mixed layer and the bottom layer, are also likely to increase in the future. Temperatures at the bottom of the lake are projected to rise 3.6°F by the end of the century, while the water layer between the surface and the bottom, the mixed-layer, is expected to increase between 5.4°F and 14.4°F by the end of the century (Lehman, 2002).

Another result of longer periods of higher surface water temperatures is a weakening of the water–air temperature gradient. This has the effect of destabilizing the atmosphere above the lake, enabling faster wind speeds across the lake surface. Observations on Lake Superior show surface wind speeds increased 5% per decade since 1985. This trend is expected to continue in the future (Desai et al., 2009).

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CHAPTER 3: GREAT LAKES CLIMATE CHANGE IMPACTS AND CONSEQUENCES

The Great Lakes region will face significant challenges associated with rising temperatures, changes to precipitation patterns and extreme events, lower lake levels, warmer water temperatures, and reduced ice coverage. As indicated in the prior chapter, many of the phenomena and impacts are already being observed. These climate change phenomena will impact a number of sectors along the coast, resulting in significant social and economic consequences across the region. This guide focuses on impacts to the following sectors: water resources, the built environment and infrastructure, ecosystems, and recreation and tourism.

Resource managers and policymakers in the Great Lakes coastal areas will have new and increasingly complex challenges, as the impacts across these sectors require more comprehensive, multi-sector, and multi-agency approaches to protect and prepare vital resources. This will include addressing jurisdictional issues between local, state, and federal governments, as well as involving the private sector, academia, non-government organizations, and the public.

This chapter discusses many of the key impacts likely to be experienced across the Great Lakes region for each of these vital sectors. It is not a formal literature review of all the resources and scientific information available but rather a summary of the most current and relevant research and issues targeted to coastal resource managers and planners in the region. Throughout this chapter, case examples of government agencies and organizations planning for and taking action to adapt to both current and future impacts of climate change are also used extensively to provide an understanding of the ongoing adaptation activities within the region. A map illustrating these case examples is shown on pp. 4-5.

Dredging in harbor, Michigan City, Indiana, Lake Michigan. Credit: National Park Service. Source: EPA Great Lakes National Program Office.

Child on beach at Indiana Dunes State Park, Lake Michigan. Credit: David Riecks. Source: EPA Great Lakes National Program Office.

Purple loosestrife, Saginaw Bay, Michigan, Lake Huron. Source: NOAA GLERL.

Low water levels in Eagle Harbor, Wisconsin, Lake Superior. Credit: Kate Houston. Source: NOAA GLERL.

The Summary of Climate Change Phenomena by Sector table (Table 4) summarizes key climate change phenomena described in the previous chapter and their associated impacts and consequences by sector for the Great Lakes region. Many of the impacts and consequences will be felt across multiple sectors. This summary focuses on climate change impacts to sectors within the purview of coastal managers and planners and does not include those impacts to sectors such as public health, agriculture, forestry, or emergency preparedness and response.

Table 4: Summary of Climate Change Phenomena by Sector

Climate Change Phenomenon	Sector Affected	Associated Coastal Impacts	Associated Coastal Consequences
Increasing Temperature[1]	Water Resources	• Drought • Reduction in snowpack	• Decline in quantity and quality of freshwater • Increased water demand
	Built Environment & Infrastructure	• Heat waves • Drought • Loss of lake ice • Reduction in snowpack	• Illnesses, injuries, and loss of life • Destruction and damage to coastal property and infrastructure • Longer navigational season • Economic gains/losses
	Ecosystems	• Invasive species • Shift in species range • Changes in timing of ecological events • Loss of lake ice	• Loss/degradation/alteration/migration of coastal ecosystems and the goods and services they provide
	Recreation & Tourism	• Heat waves • Invasive species • Shift in species range • Changes in timing of ecological events • Loss of lake ice • Reduction in snowpack	• Extended park/beach/boating seasons • Reduced snowmobiling/ice fishing seasons • Economic gains/losses • Loss/degradation/alteration of coastal ecosystems and the goods and services they provide
Changing Precipitation and Extreme Events	Water Resources	• Flooding • Introduction of toxics • Drought • Nonpoint source pollution • Pathogens and disease	• Illnesses, injuries, and loss of life • Destruction and damage to coastal property and infrastructure • Loss/degradation/alteration of coastal ecosystems and the goods and services they provide • Decline in quality of freshwater • Economic losses
	Built Environment & Infrastructure	• Flooding • Erosion • High waves • High winds	• Illnesses, injuries, and loss of life • Destruction and damage to coastal property and infrastructure • Economic gains/losses
	Ecosystems	• Introduction of toxics • Drought • Nonpoint source pollution	• Loss/degradation/alteration of coastal ecosystems and the goods and services they provide
	Recreation & Tourism	• Flooding • Erosion • Introduction of toxics • Drought • Nonpoint source pollution	• Illnesses, injuries, and loss of life • Destruction and damage to coastal property and infrastructure • Loss/degradation/alteration of coastal ecosystems and the goods and services they provide • Decline in quality of freshwater • Economic losses

Table 4: Summary of Climate Change Phenomena by Sector

Climate Change Phenomenon	Sector Affected	Associated Coastal Impacts	Associated Coastal Consequences
Declining Lake Levels	Water Resources	• Water loss • Algal blooms	• Decline in quantity and quality of freshwater • Water dependent coastal infrastructure impairment • Economic losses
	Built Environment & Infrastructure	• Water loss • Erosion	• Navigational challenges • Destruction and damage to coastal property and infrastructure • Public trust conflicts • Reduced access to waterfront facilities • Water dependent coastal infrastructure impairment • Economic losses
	Ecosystems	• Hypoxia • Algal blooms • Invasive species • Shift in species range	• Decline in quantity and quality of freshwater • Loss/degradation/alteration of coastal ecosystems and the goods and services they provide
	Recreation & Tourism	• Water loss	• Loss/degradation/alteration of coastal ecosystems and the goods and services they provide • Destruction and damage to coastal property and infrastructure • Public trust conflicts • Economic losses
Increasing Water Temperature and Declining Ice Coverage	Water Resources	• Pathogens and disease • Introduction of toxics • Harmful algal blooms	• Decreased water quality
	Built Environment & Infrastructure	• Erosion • Loss of lake ice	• Destruction and damage to coastal property and infrastructure • Expanded navigation season • Economic gains/losses
	Ecosystems	• Hypoxia • Harmful algal blooms • Invasive species • Shift in species range • Changes in timing of ecological events • Loss of lake ice	• Loss/degradation/alteration/migration of coastal and marine ecosystems and the goods and services they provide • Economic losses
	Recreation & Tourism	• Invasive species • Shift in species range • Loss of lake ice	• Extended park/beach/boating seasons • Reduced snowmobiling/ice fishing seasons • Loss/degradation/alteration/migration of coastal and marine ecosystems and the goods and services they provide • Economic gains/losses

[1] *All the phenomena listed here are driven by increasing air temperature.*

WATER RESOURCES

Key Impacts and Consequences

- Overall warmer temperatures and seasonal precipitation shifts will affect groundwater supply levels.
- Higher water demand, with inter- and intra-regional conflicts, is possible.
- More runoff is expected during winter and spring, potentially contributing to seasonal flooding; less runoff is predicted during summer during the period of highest demand.
- Communities, infrastructure, and agricultural crops are at increased risk to damage from more frequent and severe floods.
- Combined sewer overflows are projected to rise, increasing the incidence of human exposure to contaminated drinking and lake water, with recreational and economic impacts.
- Lower lake levels will expose community water intakes to the freeze-thaw cycle, invasive species, and algal production.

The Great Lakes are the Earth's largest surface freshwater system, containing 21% of the world's surface freshwater supply (EPA, 2011). This water is essential to human welfare, economic activities, and ecosystem functions in the region. Climate change phenomena will affect the rate of evapotranspiration (the return of water from the Earth's surface to the atmosphere), the quantity and timing of runoff, and the amount of water that percolates into the ground. Changes to these processes will result in significant impacts to and consequences for the region's water resources.

Water Supply

Water supply management in the Great Lakes region balances the needs of many users, providing drinking water to communities, water for commercial and industrial use, and irrigation water for agriculture. Warmer temperatures, a change in the seasonal distribution of precipitation, drought, and declining lake levels will impact water availability in the region, making planning for long-term water supply more difficult (Winstanley et al., 2006).

Groundwater provides drinking water to 8.2 million people, 43% of the agricultural water, and 14% of the industrial water in the Great Lakes basin (International Joint Commission, 2010), and it is sensitive to changes in temperature and precipitation. Climate change will affect the timing, duration, and magnitude of regional precipitation. Winter precipitation is expected to increase across the Great Lakes region (Hayhoe et al., 2009; NECIA, 2006), providing more water for runoff and evaporation (NECIA, 2006; Cherkauer & Sinha, 2010). As winter temperatures rise and with fewer days below freezing, more precipitation will fall as rain, less snow accumulation will occur, and snow will melt earlier in the springtime (Barnett et al., 2005; NECIA, 2006). These factors will lead to higher soil moisture, more groundwater recharge, and additional runoff during the winter and spring (NECIA, 2006; Cherkauer & Sinha, 2010).

The summer and fall months will likely have warmer temperatures and less precipitation, resulting in declining soil moisture, groundwater recharge, and runoff and increasing evapotranspiration. During this period, water levels, surface and ground, will fall when water demand is highest and water shortages are possible (International Joint Commission, 2003; NECIA, 2006). Along with average changes in temperature and precipitation, specific events such as droughts and heat waves will impact groundwater supplies, especially shallow aquifers (Hall & Stuntz, 2007; International Joint Commission, 2003).

An important factor to be considered in water supply planning is the occurrence of drought (Winstanley et al., 2006). During periods of drought, water availability decreases and water demand increases. Climate change could increase

Detroit waterfront. Source: NOAA GLERL.

the frequency and severity of droughts in the Great Lakes region as temperatures rise and precipitation and stream flow decline during the summer (Gamble et al., 2008; NECIA, 2006). Drought could lead to significant social and economic losses, straining regional water resources used by urban centers and agricultural communities and creating conflicts over water resource use and allocation.

Current and future withdrawals from the Great Lakes and surrounding watersheds will also be affected by a changing climate. Illinois, as an example, takes over two billion gallons of water from Lake Michigan daily to aid the flow of the Chicago and Illinois Rivers and supply water to the Chicago metropolitan area. This activity accounts for an annual 0.23 foot decrease in the overall level of the lake. Since the flow of water from Lake Michigan depends on gravity, lower lake levels in the future could affect the diversions. Although this amount is limited by a decree from the U.S. Supreme Court, the withdrawal amount has been altered by the Supreme Court in the past (Winstanley et al., 2006; Changnon, 1993).

Along with changes in water supply, demands for water will likely increase with warmer temperatures and other factors such as higher per capita income (Dziegielewski et al., 2004), potentially straining existing water supplies. Average summer temperatures are a significant variable in water use. A 1% increase in summer temperature increased per capita water use by 1.2% in Illinois and 1.1% in Michigan (Dziegielewski et al., 2004). By the end of the century, summer temperatures are expected to rise 10°F or more in certain portions of the region for a higher emissions scenario (Hayhoe et al., 2009), resulting in higher water demand.

The Great Lakes region must also consider the potential water crises in other regions. Water supply changes and droughts across the central, southwestern, and western United States could lead to renewed efforts to divert water from the Great Lakes and shift irrigation dependent agriculture towards the region (Hall & Stuntz, 2007; Dempsey et al., 2008).

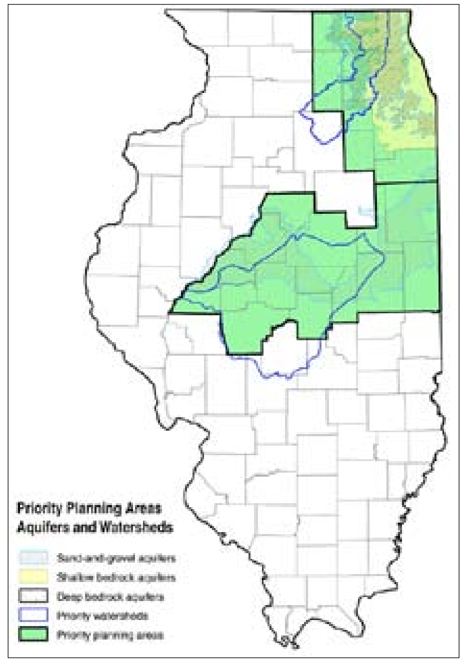
For more information on climate change adaptation measures, *Adapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for water supply management starting on page 95. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf.

Case Example

Illinois State Water Survey Water Supply Planning

Understanding what global climate change means to Illinois and providing that information to decision makers, planners, and engineers

In 2006, given increasing demands on Illinois' water resources and the recurring impacts of drought, the Illinois governor issued an executive order calling for the creation of state and regional water supply plans, including pilot plans for two high-priority areas. The Illinois State Water Survey (ISWS) worked with the Illinois Department of Natural Resources' Office of Water Resources, the Illinois State Geological Survey, and other agencies to understand water supply and demand over the next 50 years, developing information for decision makers, water supply managers, and engineers to use in creating regional water supply plans.



Priority planning areas, aquifers, and watersheds. Source: Illinois State Water Survey.

To provide water supply information for the planning process, the ISWS collected and interpreted historic and future climate information. They reviewed climate change scenarios to understand the impacts of climate change on surface water and groundwater. Along with potential changes in mean precipitation and temperature, the agency looked at the effects of short- and long-term drought scenarios, drawing on the historic record to understand the range of possibilities.

The ISWS found that future uncertainties in climate conditions result in uncertainties for hydrological conditions and water availability, making it difficult for water supply managers to plan. As a result, key recommendations were to evaluate whether existing facilities could provide water supplies during severe droughts that occurred in the past before the facilities were constructed, and for managers to plan for the possibility of more severe droughts in the future. Building these data into scenarios for water supply planning will make facilities more resilient to future droughts in the state.

Related Resources

- The Water Cycle and Water Budgets in Illinois: A Framework for Drought and Water-Supply Planning. http://www.isws.illinois.edu/iswsdocs/wcwbiil/WaterCycleandWaterBudgetsinIL.pdf
- Illinois Water Supply Planning. http://www.isws.illinois.edu/wsp/climate.asp
- Potential Impacts of Climate Change on Water Availability. http://www.isws.illinois.edu/iswsdocs/wsp/climate_impacts_012808.pdf
- Climate Change and Associated Changes to the Water Budget. http://www.isws.illinois.edu/iswsdocs/wsp/WinstanleyWendland_07.pdf

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Water Quality

The Great Lakes watershed provides drinking water to millions of people and supports countless species of fish and wildlife. Warmer temperatures, changes in precipitation, lower lake levels, and increased water temperature will negatively affect water quality in the Great Lakes region by increasing nonpoint source pollution, introducing toxics, lengthening the periods of stratification, and facilitating harmful algal blooms. These impacts threaten to expose humans to more pollutants and alter aquatic ecology, while potentially requiring greater management costs to achieve current water quality goals.

As intense precipitation events increase, nonpoint source pollution will detract from water quality in the Great Lakes basin. Higher intensity rainfall events carry more nitrates, phosphorous, and pesticides from urbanized and agricultural lands to streams and the Great Lakes. This impact will be more pronounced in the spring, when vegetative cover is at a minimum and increased precipitation is likely (International Joint Commission, 2003; Dempsey et al., 2008).

An increase in pollutant loads may result in higher management costs to meet federal water quality goals. With declining lake levels and lower stream flows, water bodies may receive smaller concentrations of pollutants before becoming contaminated. As a result, treatment costs will increase to meet existing water quality goals in the Great Lakes region (International Joint Commission, 2003).

Harmful algae bloom, Pelee Island, Ohio, Lake Erie. 2009. Credit: T. Archer. Source: NOAA GLERL.

The Great Lakes hold millions of cubic yards of sediments contaminated with persistent legacy chemicals like polychlorinated biphenyls (PCBs) and dioxins. Declining lake levels may expose these sediments to erosion, releasing contaminated sediments into the air and lake and potentially exposing humans, fish, and wildlife to higher levels of the chemicals found in the sediments. Warmer water temperatures have also been found to remobilize chemicals like PCBs in lake water. Higher water temperatures, as a result of climate change, may aid the release and movement of these chemicals in lake water and potentially introduce greater concentrations of the chemicals into the aquatic food web (Dempsey et al., 2008).

The impact of climate change on water quality will also lead to the loss and degradation of sensitive aquatic ecosystems. Warmer air and water temperatures will result in an earlier break up of lake ice and a longer summer lake stratification season. Stratification during the warmer months prevents oxygen from reaching bottom water layers, increasing the risk of oxygen-poor or oxygen-free zones as the stratification period becomes longer. These zones often lead to dead zones that kill fish and other aquatic species, while depriving other organisms of the necessary nutrients for survival (Karl et al., 2009).

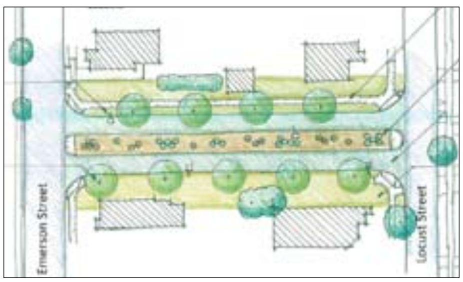
Lower lake levels and warmer water temperatures are also expected to increase the production of algae in nearshore areas, potentially leading to more frequent and widespread algal blooms (Kling et al., 2003; Dempsey et al., 2008). Since many communities have water intake valves and wells offshore, an increase in algal production may degrade the quality, taste, and odor of drinking water (Sousounis et al., 2000; International Joint Commission, 2003). While the water is treatable, this will increase treatment costs for water suppliers and water rates for consumers (International Joint Commission, 2003).

Case Example

City of Rochester Green Infrastructure Initiative

Improving water quality, reducing energy costs, and promoting social equity

In 2009, the City of Rochester, New York, launched the Green Infrastructure Initiative to reduce stormwater runoff into the combined stormwater and sewer system and minimize the number of overflow events into the Genesee River, Irondequoit Bay, and Lake Ontario. Rochester received a $2 million grant from the New York Department of Environmental Conservation to start four projects: City Hall green roof and porous asphalt parking lot, Emerson to Locust Street green connector, Cornerstone Park green retrofits, and porous tree pits. Not only will these projects improve water quality, but they will provide other local benefits such as lower energy costs, green space preservation, and air quality improvements, often to low-income neighborhoods.



Emerson - Locust green connector street. Source: City of Rochester.

A highlight of the Green Infrastructure Initiative is the Emerson to Locust green connector street project. The City of Rochester is currently building the street on vacant, city-owned land in an environmental justice area. The area will be constructed with porous streets and sidewalks, and it will house a 2,000-square-foot rain garden, a 2,000-square-foot bioswale, and street trees. These green components will utilize special materials or natural vegetation to act as sediment filters, capturing sediments and pollutants before they enter the stormwater and sewer system during rain and snowfall events.

The street is the first of its kind in Rochester, and it will be a prototype for future green streets. While the street will manage water quality and quantity, it will also provide a number of co-benefits from cutting down on response time for police and fire, to minimizing the heat island effect in the neighborhood. Rochester expects construction to begin during 2012.

Other Rochester Green Infrastructure Initiative projects:

City Hall green roof and porous asphalt parking lot	Replacing the 12,900 square foot roof on a City Hall building with a green roof and changing the parking lot paving materials
Cornerstone Park green retrofits	Replacing 4,500 square of brick walkway with porous pavement, adding rain gardens and open swales
Porous tree pits	Planting 500 new trees, 50 with porous tree pits, removing 18,000 square feet of impervious surface

Related Resources

- Building a Green Street-The Emerson and Locust Connector. http://www.cityofrochester.gov/article.aspx?id=8589947107
- Project Scope-Emerson and Locust Connector. http://www.cityofrochester.gov/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=8589947104

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Stormwater Infrastructure

Climate change is projected to increase the number of extreme rainfall events in the Great Lakes region and shift peak runoff to winter and early spring, increasing pressure on aging stormwater systems to manage larger seasonal peak runoff volumes and prevent flooding and overflows. These climatic factors will be exacerbated by the conversion of undeveloped and agricultural land to hard, impervious surfaces. The anticipated increase in flooding will cause more damage to communities and agricultural lands, result in additional illness and loss of life, and diminish water quality.

Total annual runoff is projected to increase in the Great Lakes region by the end of the century, but runoff will vary significantly by season (Cherkauer & Sinha, 2010; NECIA, 2006). As winter temperatures rise, more precipitation will fall as rain, less snow accumulation will occur, and snow will melt earlier in the springtime (Barnett et al., 2005; NECIA, 2006). In the Midwest, winter and spring total runoff, as shown in Figure 7, is expected to rise between 20% and 60% by the end of the century, while summer and fall runoff may fall (Cherkauer & Sinha, 2010).

Although increases in runoff can have positive implications, an increase in winter and spring runoff will shift peak stream flow earlier in the year, intensify daily stream flows, and increase the total number of high-flow days, which may increase the possibility of flooding (Cherkauer & Sinha, 2010; NECIA, 2006). By century's end in the upper Midwest, it is projected that there will be an overall 22% (16 days) to 31% (22 days) increase in high stream flow days during the winter and spring (Cherkauer & Sinha, 2010). These higher peak stream flows may increase the possibility of flooding. For instance, higher winter stream flows increase the frequency of ice jams, which can result in major flooding and infrastructure damage (NECIA, 2006).

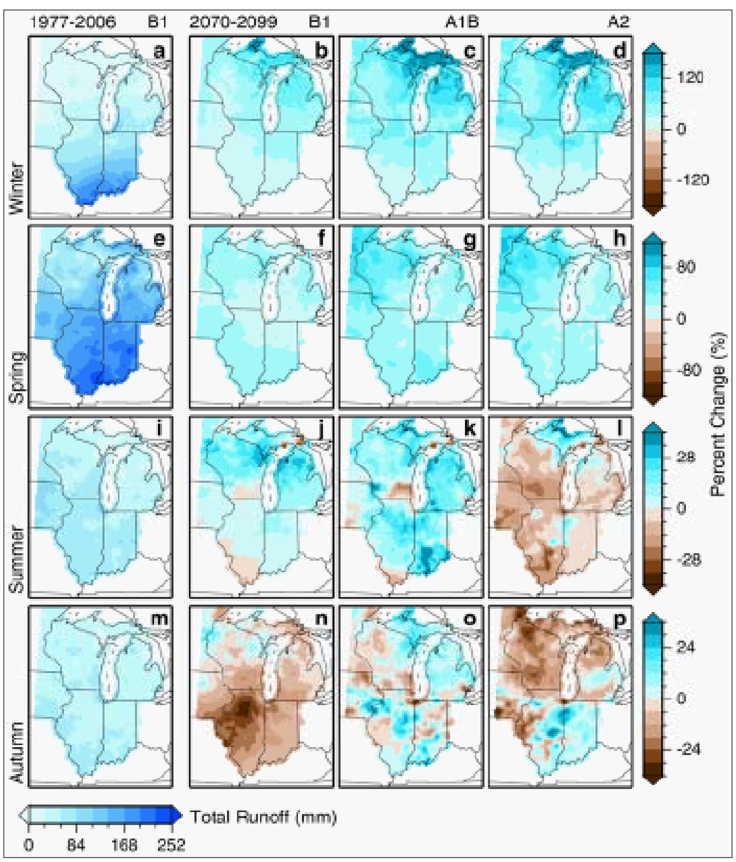

Figure 7: Percent change in average seasonal runoff for higher and lower emissions scenarios from the 1977-2006 average for the Midwest. Source: Cherkauer & Sinha, 2010.

The effect of regional climatic changes on runoff and stream flow will be exacerbated by the conversion of undeveloped and agricultural land to hard, impervious surfaces in the Great Lakes basin. Impervious surface is expected to continue growing in the future, increasing runoff, intensifying stream flow, and escalating flood risk. In an evaluation of climate change scenarios for the Huron Watershed, runoff is projected to rise from 17.1% to 21.4% by 2099 (Barlage et al., 2002). Of this 4.3 percentage point increase, 2.5% is attributed to climate change and 1.6% is credited to land use change (Barlage et al., 2002).

The stormwater infrastructure built to store and convey urban runoff is designed based on historical events. In the Great Lakes region, a shift in peak stream runoff to winter and early spring, combined with an increase in heavy precipitation events and more impervious cover, may increase the number of storm events that exceed historical design standards and *(Continued on p. 29)*

Case Example

Milwaukee Metropolitan Sewerage District and The Conservation Fund Greenseams Program

Protecting key lands to help prevent future flooding and enhance water quality

In 2001, the Milwaukee Metropolitan Sewerage District (MMSD) and The Conservation Fund (TCF) established the Greenseams program to purchase flood-prone, lowland properties with hydric soils in Milwaukee, Ozaukee, Washington, and Waukesha counties. The land acquisition program targets properties in rapidly growing communities to limit development and allow natural stormwater infiltration and filtering of nonpoint source pollution. By increasing natural infiltration and filtering, the MMSD lowers the amount of stormwater traditional infrastructure moves during storm events and decreases the risk of flooding. The areas are placed into a conservation easement managed by TCF, and the land will remain as open space in the future.

Source: Milwaukee Metropolitan Sewerage District.

To date, Greenseams has purchased over 2,200 acres of land at a cost of $22 million. It combined funding from MMSD, the Wisconsin Department of Natural Resources Knowles Nelson Stewardship Program, Wisconsin Coastal Management Program, and the North American Conservation Wetlands Act for land purchases.

Along with purchasing the land, Greenseams also restores natural vegetation to better absorb runoff and filter nonpoint source pollution. Over 400 acres of agricultural land has been converted into native wetland, prairie, and forest habitats, providing wildlife habitat and increasing the long-term resilience of regional ecosystems to a changing climate.

Protecting and managing Greenseams land also reduces greenhouse gas emissions by storing carbon in plants and soils. Using forestry protocols developed by the Climate Action Reserve, MMSD is currently evaluating the carbon sequestration potential of Greenseams property.

Related Resources

- Greenseams: Flood Management in Milwaukee | The Conservation Fund. http://www.conservationfund.org/project/greenseams_program

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Stormwater Infrastructure

(Continued from p. 27)

overwhelm these stormwater systems. As a result, more communities, infrastructure, and agricultural crops near rivers and lakes will be exposed to damage from flooding, continuing the trend in these events observed in recent decades.

Since 1983, flood losses in the Midwest have averaged $1.48 billion annually (2000 dollars) and are increasing at the fastest rate of all regions in the United States (Changnon & Kunkel, 2006). In the last 15 years the Midwest witnessed two record breaking floods—1993 and 2008 (National Climatic Data Center, 2008).The Great Flood of 1993 inundated over 20 million acres of land primarily along the Mississippi River, resulting in the evacuation of 54,000 people and losses estimated between $15 billion and $20 billion (U.S. Geological Survey, 2008a). For more information on the 2008 flood, see "Looking to the Past" on page 29.

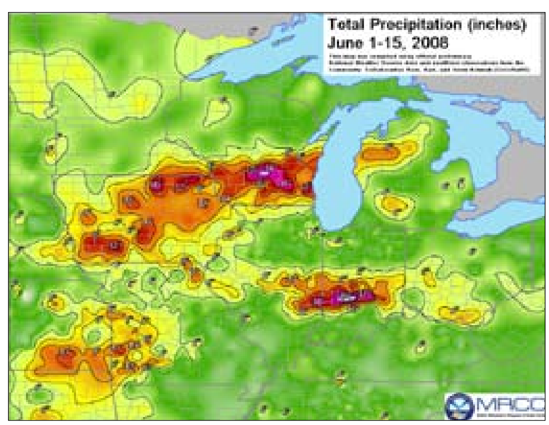
Heavy rainfall events can also lead to stormwater discharge of containments into streams and lakes (Patz et al., 2008; Dempsey et al., 2008; EPA, 2007). Of particular concern are communities with combined stormwater and sewer systems, where intense rainfall and heavy snowmelt events can exceed the capacity of the infrastructure and carry a mix of bacteria and nitrogen into water bodies (American Society of Civil Engineers, 2009; Patz et al., 2008). These combined stormwater and sewer overflows (CSOs) discharge sewage into surface water, exposing humans and ecosystems to polluted lake water and causing disease, illness, and death (EPA, 2007; Patz et al., 2008). Since many communities extend drinking water intakes into the Great Lakes, polluted water can also enter the drinking water system during a CSO. If the water is improperly treated, it can be transported to homes and businesses, potentially exposing humans to waterborne disease.

Looking to the Past

Flooding in the Midwest, 2008

The Midwest received an extended period of rainy weather along with several days of exceptionally high precipitation in 2008. Milwaukee observed 12.27 inches of rain during June, its highest monthly total in recorded history. Between June 7th and 8th, Milwaukee received 7.18 inches of rainfall within one 24-hour period, the third highest 24-hour precipitation period on record for the city (NOAA, 2009).

The rainfall coupled with moist soil conditions resulted in record stream heights and flows recorded at 21 stream gauges across southern Wisconsin. In many of these locations, streams exceeded the 500-year storm (U.S. Geological Survey, 2008b).



Source: Midwest Regional Climate Center.

The flooding caused interstate and local road closures, blew manhole covers off, washed out sections of road, and damaged businesses and homes. By 2009, $55.6 million in federal and state disaster grants and $48 million in loan assistance was provided to businesses and individuals in Wisconsin. Another $70 million was approved for public assistance projects to state and local government agencies (Federal Emergency Management Agency, 2009).

During the summer of 2009, the Great Lakes region lost over 3,000 beach days to closings or health advisories, the second highest year recorded (National Resources Defense Council, 2010). It's not certain what the economic costs are for an individual beach closure day; however, a study of Indiana Dunes State Park on Lake Michigan estimated a closure for that park of up to $35,000 per day in lost benefits (Rabinovichi et al., 2004).

In the Great Lakes region, 182 communities have combined stormwater and sewer systems, including large population centers such as Milwaukee, Wisconsin; Chicago, Illinois; Cleveland, Ohio; Detroit, Michigan; and Toledo, Ohio. In a screening-level evaluation of the effect of climate change on CSOs, by century's end, it is estimated that the regional average annual frequency would increase between 13% and 70% relative to the historical average of four events per year. CSOs would occur between 4.5 and 7.1 times per year across the region, recognizing that some locales will experience more overflow days than the average and others will experience fewer (EPA, 2007).

In Chicago, approximately 2.5 inches of rainfall in a day is the threshold for a CSO into Lake Michigan. Between 1961 and 1990, Chicago saw 2.5 extreme rainfall events per decade that exceeded the threshold. Over the next 30 years, this number is expected to rise between 1 to 1.5 events per decade. By century's end, rainfall events of more than 2.5 inches in a 24-hour period are projected to occur every other year (Chicago, 2008).

Grand River plume. Credit: Philip J. W. Roberts. Source: NOAA.

For more information on climate change adaptation measures, *Adapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for stormwater management and green infrastructure starting on page 93. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf

Looking to the Past

1993 Cryptosporidium Outbreak Milwaukee, Wisconsin

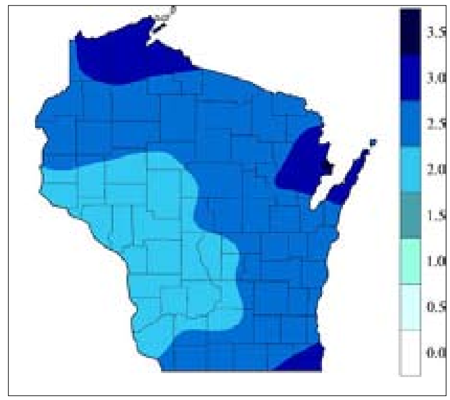
During March and April 1993, Milwaukee, Wisconsin experienced a massive cryptosporidium outbreak, which made 403,000 people ill and resulted in as many as 53 deaths (Hoxie et al., 1997). Contaminated water obtained from Lake Michigan by one of the Milwaukee Water Works plants entered the drinking water distribution system (Hoxie et al., 1997) and coincided with record high flows in the Milwaukee River (Patz et al., 2008). Lake Michigan was the source of the cryptosporidium, which was insufficiently removed at the water treatment plants (Hoxie et al., 1997). The estimated total cost of outbreak-related illness was $96.2 million, including $31.7 million in medical costs and $64.6 million in productivity losses (Corso et al., 2003).

Case Example

Milwaukee Metropolitan Sewerage District, the University of Wisconsin-Milwaukee Great Lakes WATER Institute, the University of Wisconsin-Madison, and the Southeastern Wisconsin Regional Planning Commission Downscale Models for Infrastructure Planning

Collaborating to model the effects of climate change on combined stormwater and sewer overflows, sanitary sewer overflows, and water quality

To understand how changing climatic conditions will affect regional water quality, the Milwaukee Metropolitan Sewerage District (MMSD) has undertaken a collaborative project with the University of Wisconsin-Milwaukee Great Lakes WATER Institute, the University of Wisconsin-Madison, and the Southeastern Wisconsin Regional Planning Commission to model the effects of future changes in precipitation on combined stormwater and sewer overflows (CSOs) and sanitary sewer overflows (SSOs) in the MMSD service area. MMSD estimates that 1.75 inches of rainfall during a 24-hour period is the threshold for CSOs into Lake Michigan. The MMSD recognizes that changes to winter and spring precipitation and snowmelt could affect the number, duration, and frequency of CSOs and SSOs.



Projected change in the frequency of 2+ inch precipitation events (days/decade) from 1980 in 2055. Source: WICCI.

The project uses downscaled climate data derived from the Wisconsin Initiative on Climate Change Impacts (WICCI) process (for more information on WICCI, see the case example on page 68), layering it onto a calibrated model of the MMSD wastewater conveyance, storage, and treatment system. Two downscaled precipitation and air temperature time series representing mid-21st century climate change conditions, one in the upper 90th percentile for 1.75-inch spring precipitation events and one in the lowest 10th percentile, capture a range of possible outcomes.

After learning about the global circulation models and the downscaling process, the partners are cautious about how to use this early round of model results. For instance, while most circulation models show an increase in spring precipitation, the amount often varies significantly based in part on the underlying model assumptions. Results of the downscaling effort will be used as a tool to help decision makers understand how climate change could affect rainfall events, CSOs, SSOs, and water quality, and will contribute to discussions regarding the degree of uncertainty in translating global circulation models to local scale assessments.

Related Resources

- Milwaukee Metropolitan Sewerage District's 2035 Vision. http://v3.mmsd.com/NewsDetails.aspx
- Southeastern Wisconsin Regional Planning Commission Climate Change. http://www.sewrpc.org/SEWRPC/Environment/ClimateChange.htm

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BUILT ENVIRONMENT AND INFRASTRUCTURE

Key Impacts and Consequences

- Coastal erosion and recession rates due to heavier and earlier seasonal precipitation events and storm surges with less lake ice coverage will increase the risk of damage to homes, buildings, and other infrastructure.
- Lower lake levels may expand beaches and encourage public use, resulting in new conflicts over property rights.
- Increases in storm and wave intensity and lower lake levels are anticipated to result in higher infrastructure maintenance and dredging costs for commercial ports and recreational marinas.
- Flooding, coastal erosion, and bluff failures are expected to increase road closures and result in more maintenance and repairs, while increases in heavy rainfall events could contribute to an increase in accidents and fatalities.
- Higher annual temperatures will increase cooling needs, placing increased demand on utility generators, building construction, and maintenance and operation considerations.
- Climate change will affect nearly all aspects of energy production, delivery, and consumption in the Great Lakes region.

Nearly all communities across the Great Lakes region will need to adapt to the impacts of climate change during this century. Increasing temperatures and changes to precipitation patterns will alter coastal flooding and erosion rates and result in more damage to property, buildings, and infrastructure and potentially cause injuries and loss of life. Declining water levels will expand the shoreline and encourage more public access, potentially triggering new conflicts over property rights. Climate change will also affect the transportation and energy sectors. Lower lake levels will result in damage to aging water transportation infrastructure, require additional dredging, and increase shipping costs. Energy generation, transmission and distribution systems will need to withstand more excessive heat days, forceful winds, and heavy precipitation events, as well as support increases in energy demand due to warming temperatures.

Coastal Development

Coastal erosion constantly shapes and reshapes beaches, shorelines, and bluffs around all the Great Lakes, resulting in new land forms but also damaging property, infrastructure, and buildings and placing people at risk to injury and loss of life. Some of the climatic factors that cause erosion, like precipitation and waves brought by winter cyclones, have increased significantly during the 20th century (Angel & Isard, 1998) and will likely be exacerbated by regional climate change. Long-term lake level decline, previously experienced as seasonal and inter-annual episodes, is also expected to increase coastal erosion and recession rates along Great Lakes shorelines. These climate change phenomena and their associated impacts, coupled with community and economic pressure to urbanize lakefront areas, will increase the number of people, buildings, and infrastructure exposed to the impacts of climate change.

Changes in air temperature and precipitation patterns are anticipated to increase the frequency and intensity of storm events and wave conditions across the Great Lakes, both of which are already primary contributors to shoreline erosion and property loss (Keillor et al., 2003). Wave power is related to wind speed, wind duration, and open water distance over which the wind is in contact with the water surface (fetch). During recent decades, wind speeds have increased over the Great Lakes. Over Lake Superior, wind speeds increased by 5% per decade since 1985, exceeding wind speeds on shore due to the destabilization of the air-water temperature gradient (Desai, et al., 2009). Higher wind speeds may drive faster surface currents in the future.

Wave power will also be aided by reduced ice cover on the Great Lakes and may expose coastal communities to more damage from storms. Less ice coverage will provide more open water distance and a longer portion of the year for winds to contact the water surface, potentially increasing the suitable conditions for powerful waves. Additionally, average ice duration and ice coverage is expected to decline on the Great Lakes, affecting winter shoreline erosion. Nearshore ice deflects wave energy away from the shoreline, protecting the beach from erosion (Keillor et al., 2003). However, recent winters with less ice on the Great Lakes and Gulf of St. Lawrence increased coastal infrastructure exposure to damage from winter storms (Forbes et al., 2002).

Beach erosion after a storm, Lake Michigan. Source: NOAA GLERL.

Case Example

Bay-Lake Regional Planning Commission Hazard Mitigation

Providing guidance to local governments in the coastal zone about the impact of climate change on hazard frequency and intensity during hazard mitigation planning

In conjunction with the Wisconsin Coastal Management Program, the Bay-Lake Regional Planning Commission (RPC) works with counties in the Northeast Wisconsin Region along Lake Michigan and the local hazard mitigation steering committees to develop mitigation plans. The RPC recognized that the city and county's hazard mitigation plans did not note that climate change will affect the frequency and intensity of hazard events such as temperature extremes, severe storms, floods, and droughts.

To address this issue, the RPC increased their mitigation planning support services by incorporating a discussion of climate change into *A Guide for Hazard Mitigation Planning for Wisconsin Coastal Communities* and began providing climate change information to emergency managers and planners to help them more fully prepare for more frequent and severe impacts. As the community develops mitigation actions, projects are prioritized in part based on the likely impacts from each hazard.

Related Resources

- A Guide for Hazard Mitigation Planning for Wisconsin Coastal Communities. http://www.baylakerpc.org/media/46893/coastal%20hazards%20planning%20guide_june%202007.pdf

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Communities and homes that dot the bluffs around the Great Lakes will also be affected by warmer temperatures and more winter and spring precipitation that impact erosion rates. It is anticipated that these conditions will result in more deep rotational slumps, translational slides, mud flows, sheetwash, and other soil creep when coupled with more freeze/thaw events (Table 5 summarizes selected climate changes and their anticipated effects on erosion). More intense precipitation events may also increase erosion rates, particularly during winters without frozen soils, in summers and falls with drier soils, and during periods of drought (Luloff & Keillor, in review).

Coastal erosion, Indiana, Lake Michigan. Credit: National Park Service. Source: EPA Great Lakes National Program office.

Table 5: Selected Climate Changes and Their Anticipated Effects on Erosion of Cohesive Slopes (from Luloff & Keillor, in review)

Climate change	Potential deep rotational slumps	Typical shallow translational slides	Solifluction (mud flows)	Sheetwash and rill erosion	Soil creep (mostly Lake Superior slopes)
Warmer, wetter winters, more freeze/thaw events	More failures only if shallow frost penetration thaws	More slides	More mud flows	More erosion	Even more erosion, weaker soils
Much warmer, wetter winters, no freeze/thaw	More failures	More slides	More mud flows	More rain impact, more erosion	Even more erosion, weaker soils
More intense precip. events in winter with frozen soil[1]	No effect	No effect	No effect	No effect	No effect
More intense precip. events in winter without frozen soil	More failures	More slides	More mud flows	More erosion	Even more erosion, weaker soils
More intense precip. events with dryer summer, fall, soils	No effect	More slides	No effect	More erosion	Even more erosion, weaker soils
No ice cover on lakes[2]	More failures	More slides	No effect	No effect	No effect
Short-term drought[3]	No effect	More thin slides	More erosion	More erosion	Uncertain
Severe drought: years or longer[3]	Initial fewer failures, long term uncertain	More slides	More erosion	More erosion	Uncertain

[1] *Presumes face of slopes remain frozen during intense precipitation events*
[2] *Presumes more wave attack with storm waves reaching base of slopes*
[3] *Presumes occasional or rare intense precipitation events. Uncertainty about the net effect of drought on slope stability.*
The authors adapted the table from Chase, 2007 and Edi & Mickelson, 2007.

Case Example

New York State Guidelines for the Development of Coastal Resilience Plans

Reducing the vulnerability of communities to coastal storms and erosion through planning and adaptation strategies

Recognizing the growing exposure of coastal areas to storms and climate change impacts, the New York State Department of State (DOS) collaborated with the NOAA Coastal Services Center to develop guidance to reduce coastal hazard risks through Coastal Resilience Plans (CRPs). In the CRPs, DOS works directly with local governments to develop comprehensive land and water use plans to improve community resilience and address flooding and other hazards. The new CRP guidance, to be published in 2011, provides a means to identify economic, socio-cultural, and environmental assets at risk, with a focus on sustaining community functions and values.

The DOS CRP guidelines assist local governments through a risk assessment process to select preferred actions and form a long-term management plan. By means of long-term planning communities can transition to sustainable development practices. The CRPs use a comprehensive approach to hazard management that integrates coastal hazard resilience and climate change into community decisions. Existing planning processes such as comprehensive land use, Local Waterfront Revitalization Programs, capital development, and post-storm reconstruction can be used to reduce the future risks associated with coastal storms, erosion, and sea level rise. The CRP resource outlines and describes several key considerations including risk assessment, measuring resilience, adaptive measures, coastal hazard resilience planning, adaptive management, and implementation resources. The process can be extended to a regional or inter-municipal approach if desired.

Related Resources

- New York State Division of Coastal Resources. http://www.nyswaterfronts.com/waterfront_natural_flooding.asp

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Lake levels also have an important effect on lakebed erosion and bluff slope stability, which threatens property and structures along the shoreline. When lake levels are low, the zone where waves break is further offshore, resulting in erosion further from the shoreline (Keillor et al., 2003; Ohm, 2008). When higher water levels return, the water depth close to shore is greater, potentially resulting in greater wave power and erosion on the shoreline (Keillor et al., 2003; Ohm, 2008). While shoreline erosion is less during periods of low water levels, except in the nearshore area, an increase in lake levels will start erosion that will continue during periods of declining water (LaValle, 2000).

For more information on climate change adaptation measures, *Adapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for growth and development and loss reduction starting on page 64 and 69 respectively. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf

Case Example

Ohio Balanced Growth Program

Managing growth to protect natural resources and water quality in a changing climate

In the 2000 *Lake Erie Protection & Restoration Plan*, the Ohio Lake Erie Commission (OLEC) recommended creating a task force to develop strategies that balance the protection of the Lake Erie watershed with continued economic growth. The task force recommended, and the OLEC adopted, the Balanced Growth Program, a voluntary, incentive-based initiative to manage growth in the watershed. Launched in 2006, the program develops watershed-based planning partnerships among local communities and provides land use best practices for minimizing impacts on water quality. The success of the voluntary program around Lake Erie prompted the Ohio Water Resources Council to implement the program statewide in 2009.

Cleveland. Source: Ohio Balanced Growth Program.

The Balanced Growth Program enables Lake Erie communities to build adaptive capacity to climate change. The program identifies model regulations, codes, and standards for best local land use practices, including conservation development, stormwater management, riparian and wetland protection, and coastal protection. The program provides incentives for local action by supplying technical assistance, offering extra points on 28 state grant programs, and dedicating funding for balanced growth planning.

Since the Balanced Growth Program was initiated in 2006, the OLEC updated the *Lake Erie Protection and Restoration Plan*. The updated Lake Erie plan recognizes climate change as a priority area and sets a goal to help watershed communities and land owners understand and prepare for the impacts of climate change. To aid this process, the OLEC asked the Balanced Growth Technical Advisory Committee to develop model legislation for shoreline development that recognizes climate change with input from key stakeholder groups.

Related Resources

- Linking Land Use and Lake Erie: Best Local Land Use Practices. http://balancedgrowth.ohio.gov/LinkClick.aspx?fileticket=17QB6vd7%2bZ0%3d&tabid=57
- Lake Erie Protection & Restoration Plan 2008. http://lakeerie.ohio.gov/Portals/0/Reports/2008LEPRplan.pdf

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Property Rights and the Public Trust

A long-term decline in Great Lakes water levels due to climate change is expected to increase the size of beaches but also result in new conflicts over property rights. Lower lake levels are anticipated to expand beaches by 100 feet or more along Lakes Michigan and Huron (Dempsey, 2008). Warmer spring and fall temperatures are also projected to lengthen the beach season and encourage visitation, as projected in an evaluation of climate scenarios on Sauble Beach on Lake Huron and Toronto beaches on Lake Ontario (Scott & Jones, 2010). Although larger beaches will provide more opportunities for the public to access the Great Lakes shoreline, private property owners may hope to occupy newly exposed land and limit public access to the lakes.

While lower lake levels are expected to encourage more public access, the wharves and piers of many property-owners may no longer reach the water's edge. As a result, lower lake levels are anticipated to provide the impetus for property owners to extend wharves and piers to access more distant waters, potentially interfering with public use of the shore. Similarly, these built features may impede plant and animal species as they migrate to new areas.

States use the public trust doctrine to define the extent of public and private land. The public trust doctrine is a common law concept that affirms that tidal lands and lands below navigable waters are held by the state. Under federal common law,

Duluth-Superior Harbor, Lake Superior. Credit: Minnesota Sea Grant. Source: NOAA GLERL.

the public trust doctrine encompasses navigable waters and the land beneath them to the ordinary high water mark (OHWM), and many coastal states have adopted the OHWM as the boundary to apply to the public trust doctrine. Courts have found that the Great Lakes are held in trust by the state for the use of all citizens, allowing individuals to walk on the beaches or swim, fish, and boat in the waters. The water mark is an important reference point used to manage public access, shoreline protection, and other state coastal programs.

While the public trust doctrine provides the legal framework for defining the boundary between public and private lands, states interpret the doctrine in different ways. For example, most states use the OHWM as the public trust boundary, however, some define a specific elevation such as Indiana and Pennsylvania, while others use the extent of vegetation to mark the boundary like Michigan (See Table 6).

Recent court cases have altered the interpretation of the boundary for public trust protection. In

Looking to the Past

Lake Michigan Water Levels (1964-1965)

Between 1964 and 1965, Lake Michigan experienced a period of record low lake levels. While the lower lake levels resulted in impacts to shorelines and recreation as well as shipping, industry, and commerce, the period was followed by a rapid increase in lake levels. This rapid increase in lake levels caused significant problems for infrastructure and land management. During 1964-1965, shoreline protection structures in Chicago were exposed to air, hastening dry rot and resulting in an estimated $843 million (1988 dollars) worth of damage when higher lake levels returned. Further, lower lake levels encouraged development closer to the lower water level. When higher water levels returned, Chicago experienced damage to buildings built too close to the shoreline (Changnon, 1993).

Table 6: State Public Trust Boundaries

State	Public Trust Boundary	State Code or Court Case
Illinois	Ordinary high water mark	615 Ill. Comp. Stat. 5/24
Indiana	Ordinary high water mark, defined as a specific elevation	312 IND. ADMIN. CODE 1-1-26(2) (581.5 feet IGLD 1985).
Michigan	Natural ordinary high water mark	Glass v. Goeckel (473 Mich. 667)
Minnesota	Ordinary high water mark	MN Statue 103 G, MN Rules Chapter 61.15
New York	Mean high water mark	N.Y. COMP. CODES R. & REGS tit. 19, § 600.2(z).
Ohio	Landward boundary the water's edge	Merrill v. Ohio State Department of Natural Resources
Pennsylvania	High water mark, defined as a specific elevation. The state defined both the high and low water marks. Public access policy - providing that the public has a right of foot access along the Lake Erie shore in the "public easement area" between the ordinary high and low water marks.	25 PA. CODE § 105.3(b) (high water mark for Lake Erie is 572.8 feet IGLD, and the low water mark is 568.6 feet IGLD)
Wisconsin	Ordinary high water mark	WI Administrative Code 115.03(6)

Sources: Kilbert, 2010; personal communications with state coastal managers.

Michigan, *Glass v. Goeckel* resulted in a new interpretation of the landward boundary for public trust protection (473 Mich. 667). The case modified the jurisdiction line from an elevation-based to a feature-based delineation that referenced the Natural OHWM. This ruling stressed the lakeward limit of terrestrial vegetation and shifted the regulatory approach of the state. In *Merrill vs. Ohio State Department of Natural Resources* (case pending in Ohio Supreme Court), litigation pits property owners against advocates of shoreline access, environmental groups, and the state government. The lower court found in favor of the property owners, ruling that public trust only extends to the lake edge, excluding some portions of the shoreline and redefining the area held by the state.

How states define the public trust boundary will affect management and public access under changing climatic conditions. As an example, during periods of prolonged and declining low water levels, the vegetation line will move toward the lake. In instances where the state determines the high water line by vegetation, development may move toward the lake, exposing coastal buildings and infrastructure to an increased risk of loss during periods of seasonal or inter-decadal higher lake levels and during severe storm events (Luloff & Keillor, in review). Under these conditions, it is anticipated that many property owners will attempt to armor the newly exposed lands against anticipated erosion. If armoring occurs during a period of lower water levels, as water level rises during seasonal and inter-decadal fluctuations, then there will be a loss of shoreline and shoreline access as the water rises to the shoreline protection feature. A similar set of issues may also arise for states that define the public trust boundary by elevation.

For more information on climate change adaptation measures, *Adapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for shoreline management starting on page 78. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf

Buildings

Projected increases in the frequency, duration and severity of extreme weather conditions will impact heating and cooling demand, building design, and maintenance and operations. As temperatures rise this century, buildings will require costly retrofits to withstand higher mean temperatures and prolonged periods of high heat. Many buildings in the Great Lakes region do not have cooling systems. In Chicago, the proportion of residential structures built before 1980 with central air conditioning is only 39%, while the proportion of retail building constructed before 1980 with air conditioning is 63% (Konopacki & Akbari, 2002).

High heat may also lead to larger repair costs for roofs and building facades, as each breaks down more quickly under changing conditions. The City of Chicago, Illinois, estimates that building-related expenses for air conditioning retrofit and roof and building repair will increase significantly by the end of the century. Under a higher emissions scenario, the maintenance costs for city-owned buildings is expected to be $20 million more than under a lower emissions scenario (Hayhoe et al., 2010b).

Buildings will also be affected by an increased frequency, duration, and intensity of extreme rainfall and coastal erosion, increasing costs associated with public and private building maintenance and replacement. Coastal facilities will be particularly at risk given shoreline erosion issues discussed.

Beach erosion from a winter storm, Lake Michigan. 1985. Source: NOAA GLERL.

For more information on climate change adaptation measures, *Adapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for loss reduction starting on page 69. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf

Looking to the Past

1995 Chicago Heat Wave

In 1995, Chicago experienced an unprecedented heat wave with seven days over 90°F and two days over 100°F (Hayhoe et al., 2010b). Nighttime temperatures exceeded 80°F. Urban heat island effect, power failures, and a lack of air conditioning in older buildings contributed to over 514 heat-related deaths, with some estimates exceeding 739 deaths, and over 3,000 hospital emergency visits (Changnon, et al., 1996; Hayhoe et al., 2010b).

Transportation Infrastructure

Climate change will affect both the physical infrastructure associated with transportation such as ports, marinas, and roads, and influence travel safety. Lower lake levels and more storm events will impact the operation and maintenance of commercial ports and recreational marinas, requiring new repairs, upgrades, and dredging. At the same time, shipping companies will face higher costs to move the same quantity of goods. Warmer air temperatures, more extreme precipitation events, and reduced snow and ice formation will also affect roadway infrastructure and traffic safety. More flooding and coastal erosion is expected to contribute to more road closures and result in higher maintenance costs, while heavy rainfall may increase the number of automobile accidents and associated injuries and fatalities.

Commercial Shipping and Ports

Climate change will pose significant challenges for Great Lakes shipping companies by reducing the size of cargo loads, increasing the number of trips, and raising the cost of dredging. At the same time, it will provide new opportunities for companies to expand their shipping season, potentially offsetting some of the negative consequences of climate change.

Great Lakes shipping is very sensitive to lower lake levels as an annual mean or during periods of seasonal variation. Lower lake levels diminish the bottom clearance for shipping vessels and force cargo carriers to reduce their loads. Vessels on the Great Lakes-St. Lawrence River system operate with minimal under-keel clearance, with an allowable clearance of one foot (Millerd, 2007). A 1,000-foot lake-going ship loses 270 tons of capacity per inch of lost draft, and an ocean-going vessel of about 740-feet loses 100 tons of capacity for each inch of lost draft (Quinn, 2004). This loss of draft requires shippers to reduce their cargo tonnage and results in an estimated loss due to lighter loads of nearly $30,000 per vessel (National Conference of State Legislatures, 2008).

Great Lakes shipping. Credit: T. Johengen. Source: NOAA GLERL.

Looking to the Past

Great Lakes Water Levels and Shipping

A period of low lake levels between 1997 and 2000 affected commercial shipping across the Great Lakes region. Lower water levels meant that vessels carrying heavy materials such as iron ore, coal, cement, and limestone between ports on the Great Lakes decreased their cargo loads for fear of running aground in channels and ports (NOAA, n.d.). In 2000, for example, low water levels forced carriers into "light loading" and reduced their cargo tonnage by 5% to 8% (Caldwell et al., 2004). The lower lake levels prompted the Canadian Department of Fisheries and Oceans to allocate $15 million in emergency dredging funds for Great Lakes ports and marinas (Fisheries and Oceans Canada, 2000).

Lake Michigan water levels declined 2.95 feet between 1964 and 1965, resulting in significant costs for shipping and dredging. Lower water levels reduced shipping carrier loads between 5% and 10%, and shippers made more trips as a result. Along with direct costs to shipping companies, the US Army Corp of Engineers increased allocations for dredging in the region. Dredging costs increased 56% at Calmut Harbor, while also necessitating dredging of the Waukegan Harbor (Changnon, 1993).

To estimate the potential impact of lower water levels due to climate change on international commercial navigation, the average operating costs of different commodity groups were estimated for different water level scenarios and then compared to historic averages. For 2030, average operating costs are expected to increase between 1.9% and 7.4% depending on the commodity group, with an overall average increase of 4.8%. By the end of the century, average operating costs are projected to rise between 13.3% and 26.7%, or an average of 22.1%. Grain and agricultural product shippers are anticipated to bear a disproportionate share of the costs (~75%). Average operating costs are estimated assuming current prices for a future year (Millerd, 2007).

Higher operating and capital costs for water transport companies may also divert commodities to other transportation modes. In some cases, parallel routes do not exist in remote locations, but in others, rail and road companies may use excess capacity to move commodities. This will place additional strain on road and rail resources where capacity constraints already exist, but it may also provide economic benefits to some rail and road shipping companies.

For commercial harbors and ports, it is anticipated that lower lake levels will result in damage to aging infrastructure and require additional dredging. Storm events may also create larger waves, higher seiches, stronger wind speeds, and greater storm surges that cause damage to harbor and port infrastructure.

To evaluate the economic implications of climate change and future lake level fluctuations to harbor

Ship at ore dock, Duluth, Minnesota, Lake Superior. Credit: U.S. Army Corps of Engineers. Source: EPA Great Lakes National Program office.

infrastructure and potential costs for dredging, an assessment of the Duluth-Superior Harbor and the Toledo Harbor was conducted. The assessment included estimates for harbor entrance structure types; interior structures, such as slip walls; and dredging costs for all slips and the federal channel (Bergeron & Clark, 2011).

For Toledo Harbor, it is estimated that harbor dredging costs would be between $10.8 million and $11.9 million for all 28 slips and the federal channel, and infrastructure repair and replacement cost would range from $71.3 million to $122.8 million. For the Duluth-Superior Harbor, it is estimated that harbor dredging costs would be between $39 million and $41.2 million, and infrastructure repair and replacement would range from $177 million to $298.5 million (Bergeron & Clark, 2011).

Future channel dredging will not be easy for ports and harbors. Increasing channel depth below 27

Table 7: Potential Economic Consequences of Water Level Changes for the Toledo and Duluth-Superior Harbors-Matrix and Dredging Database Results

Harbor	Dredging Costs for All Slips and Federal Channel (per foot of depth)	Infrastructure Repair & Replacement Costs
Toledo	$10.8 million-$11.9 million for all 28 slips	Repair: $71.3 million Replacement: $122.8 million
Duluth-Superior	$39 million-$41.9 million for all 58 slips	Repair: $177 million Replacement: $298.5 million

Source: Bergeron & Clark, 2011.

feet will require authorization from Congress (Caldwell et al., 2004; Quinn 2004). Further dredging may also negatively impact human and natural systems by releasing contaminated sediments found on the lake bottom into the lake (International Joint Commission, 2003).

Climate change also presents an opportunity for Great Lakes shipping companies to extend their season as lake ice cover diminishes. Presently, the St. Lawrence Seaway and the Welland Canal are closed for approximately two months each year, and the dates are flexible based on weather conditions. Since the 1980s, there has been a gradual increase in the average open period of the St. Lawrence Seaway, increasing 10 days during that period. The Montreal-Ontario section was open for a record 283 days in 2006. A limiting factor, however, will be maintenance of the lock systems. During the 2 months the system is closed, infrastructure is repaired and upgraded. The maintenance period may be shortened by one month in the future, but every 3 to 5 years, it may need to be extended to perform more extensive upkeep (Millerd, 2007).

For more information on climate change adaptation measures, *Adapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for infrastructure starting on page 76. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf

Recreational marina, Milwaukee, Wisconsin, Lake Michigan. Credit: Lake Michigan Federation. Source: EPA Great Lakes National Program office.

Recreational Marinas

As with commercial ports and harbors, climatic changes will affect the operation and maintenance of recreational marinas. Two studies have assessed the economic impacts due to lake level declines on Lake Huron. The first examined marina dredging costs and cargo capacity impacts for Goderich Harbor, Ontario. In a scenario where lake levels decline by 3.2 feet, marina dredging costs are projected to increase by over $2 million (2004 dollars), while cargo capacity is expected to decline by 2,808 tons. If water levels drop an additional 2.5 feet, marina dredging costs are expected to increase by over $8 million and cargo capacity fall 8,640 tons (Schwartz et al., 2004).

In the second study, 58 marinas on the Georgian Bay and Severn Sound Inlet in Lake Huron were assessed for marina closings and slip losses. The study found that a one-foot water level reduction would result in 3 marina closings, a loss of 376 recreation boating slips, and reduced boating expenditures of $1.6 million. A 1.4-foot water level reduction is projected to result in 12 marina closings, a total loss of 1,141 recreational boating slips, and $4.8 million in reduced annual expenditures. A 1.9-foot drop is expected to result in 29 marinas closing, losses of 1,498 recreational boating slips, and $6.3 million in reduced annual expenditures (Stewart, 2009).

To put these two studies in perspective, by 2080, average Lake Huron water levels are projected to decline an average of 1.35 feet, with a range up to 5.7 feet under the higher emissions scenario (Angel & Kunkel, 2010).

Roadways and Traffic Safety

Warming air temperatures and more extreme precipitation events are anticipated to increase flooding, coastal erosion, and bluff failures that may contribute to increased road closures, increased repairs, more landscape planting costs, higher maintenance costs, and increased transport delays (Hayhoe et al., 2010b; Schwartz, 2010).

The City of Chicago estimated that road repairs and maintenance would double under a higher emissions scenario, in part because the materials needed for hotter and stormier weather cost 2.2 times more than traditional materials (Chicago, 2008).

In addition to affecting physical infrastructure, climate change is anticipated to have a significant

Case Example

Toronto Climate Change Risk Assessment Process and Tool

Building tools to prioritize climate change risk and identify short-term action

In July 2007, the Toronto City Council adopted the *Climate Change, Clean Air and Sustainable Energy Action Plan* for Toronto. The plan called for the city to create a climate change adaptation plan, and in July 2008, the City Council unanimously endorsed *Ahead of the Storm: Preparing Toronto for Climate Change*. The adaptation strategy outlined potential climate change impacts, short-term actions to minimize the impacts of climate change, and actions to guide the city's development of a comprehensive, long-term strategy to adapt to climate change. A key component of the long-range strategy is the development of a process to prioritize risks and then identify and implement adaptation actions.

To meet this need, the Toronto Environment Office developed a climate change risk assessment process and tool. The process and tool is a software program that enables individual agencies to systematically examine the effects of extreme events worsened by climate change and creeping events like slow temperature increases on municipal operations, services, and infrastructure. The process and tool is a "screening-level" methodology that enables agencies to identify the highest risks and prioritize actions to lower the severity of those impacts on city operations and services. This will help avoid significant future costs and disruptions that could harm businesses and individuals in Toronto.

The Toronto Environment Office is piloting the process and tool for their Transportation Services and Shelter Support and Housing Administration agencies. Using the process and tool, Transportation Services and Engineers Canada is currently conducting an engineering-level vulnerability assessment for culverts.

The Toronto Environment Office will work with other departments and regional agencies to assess risk. The office will utilize the process and tool for other city operations along with engaging non-municipal infrastructure providers such as the regional transit authority and regional utilities.

Related Resources

- Climate Change, Clean Air and Sustainable Energy Action Plan. http://www.toronto.ca/changeisintheair/pdf/clean_air_action_plan.pdf
- Ahead of the Storm: Preparing Toronto for Climate Change. http://www.toronto.ca/teo/pdf/ahead_of_the_storm.pdf

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impact on traffic safety and travel speed (Koetse and Rietveld, 2009). As precipitation increases during the winter and spring and the frequency of severe rainfall events increases across the region, the number of accidents and injury accidents is also likely to rise. In a study of Canadian cities, during periods of rain or snowfall, accidents rose by 75% and the number of physical injuries rose by 45% (Andrey et al., 2003). In a study of Midwest highways, rain and snow increased the accident rate by 10 times over dry conditions (Knapp et al., 2000).

Snowfall results in more nonfatal-injury crashes, but fewer fatal crashes than rainy days (Knapp et al., 2000). In part, this is explained by reduced traffic speeds. In a study of traffic conditions in Minnesota, rain, snow, and reduced visibility lower freeway traffic speeds up to 6% for rain, 13% for snow, and 12% for reduced visibility (Maze et al., 2006). As snowfall declines across the Great Lakes region, the number of non-fatal accidents will potentially decline.

Overturned snowplow, Indiana. Credit: Jim Koch. Source: NOAA National Weather Service.

Case Example

Northwest Indiana Regional Planning Commission Climate Change Resolution

Taking initial steps to understand and act upon the potential impacts of climate change

The Northwest Indiana Regional Planning Commission (NIRPC) covers three counties, 41 cities and towns, and three-quarters of a million people along the southwest corner of Lake Michigan. The NIRPC works with the Indiana Department of Transportation and local public transit operators to plan for transportation improvements in urbanized areas. In the fall of 2010, the NIRPC passed a resolution that initiated a process to better understand the impacts of climate change in the region and begin to incorporate climate change into regional transportation planning. The resolution recognizes that public infrastructure needs to respond to the threats from higher temperatures, altered precipitation patterns, and lower lake levels.

The resolution requests that NIRPC staff work with local universities and other partners to scale down climate models for the region; enhance public education and outreach programs, particularly those related to environmental justice; become the primary resources of communities dealing with mitigation and adaptation strategies; and weave green infrastructure into long-term planning efforts.

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Energy

Climate change will affect nearly all aspects of energy production, delivery, and consumption in the Great Lakes region. The region generates electricity from numerous sources, including hydro-power, nuclear, coal, and wind. These energy sources are sensitive to changes in temperature, precipitation and runoff, lake levels, and wind speeds. Transmission and distribution lines are vulnerable to increases in extreme weather events, including excessive heat days, higher wind speeds, and an increase in the severity of precipitation events. Demand for energy is also anticipated to grow as air temperatures increase across the region.

A change in lake levels and runoff flows into the Great Lakes will alter the generating capacity of hydro-electricity producers. In 1999, hydro-electricity production fell significantly at the Niagara and Sault St. Marie facilities, corresponding with lower river flow rates and lake levels (Canadian Council of Ministers of the Environment, 2003).

By 2050, impacts on energy production for the St. Lawrence and Niagara hydro-electricity facilities are estimated to range from a small increase in production to a large decrease in annual output, depending on precipitation patterns. Production is also expected to change seasonally, with greater generation during the spring season and lower generation in the summer. Reduced electricity generation during peak summer season is anticipated to cause prices to increase significantly (Buttle et al., 2004).

Along with mean changes in precipitation, runoff, and lake levels, extreme periods of drought will also reduce the amount of hydro-electricity power plants produce. The region is expected to see an increase in the frequency, intensity, and duration of droughts in the future. During drought periods, the amount of energy hydro-electric plants produce will fall, potentially occurring during the summer when users require more energy for cooling and demand is at its peak.

In addition to hydro-electricity plants, the Great Lakes region houses a number of nuclear power plants that will be affected by climate change. There are over 30 reactors in the United States and Canada along the lakes. Nuclear and other power plants use water to cool plants during the production of energy. After cooling the system, water is returned to the waterway or lake. As air and water temperatures warm, this type of cooling system is expected to become less efficient and require more water to do the same amount of cooling (Ackerman & Stanton, 2008).

Climate change will also affect the delivery of coal to energy generating plants. Approximately 30% of the total tonnage of commodities shipped on the Great Lakes is coal, and much of that coal is moved from ports along Lakes Erie and Superior to Nanticoke and Courtright in Ontario. As lake levels decline, this will potentially result in a volume constraint for shipping companies, forcing shippers to reduce their cargo load and increase shipments to move the same volume of coal. This is expected to raise costs for shippers who will pass the costs along to energy generating

Loading coal at the railroad docks in Sandusky, Ohio, Lake Erie. Credit: J. Delano, Library of Congress. Source: NOAA GLERL.

plants and consumers. It is estimated that climate change will increase the shipping costs of coal 16%-18% by 2030 and 24%-29% by 2050 (Millerd, 2005).

Many states around the Great Lakes region are exploring on- and off-shore wind generation. Climate change could affect wind energy production due to projected increases in lake wind speeds. Recent studies have found that changes in wind speeds appear to be highly variable across the United States with waning speeds in many locations over the last 20 years (Pryor et al., 2009). Many areas around the Great Lakes, however, observed an increase in wind speed (Pryor et al., 2009). Wind speeds increased over Lake Superior by 5% per decade, exceeding wind speeds on shore (Desai, et al., 2009). It is expected that reduced ice cover and changes to the air-water temperature gradient will facilitate higher wind speeds on the Great Lakes (Desai, et al., 2009).

Infrastructure for energy production, including transmission and distribution systems, will also be affected by climate change. More extreme weather events could result in the failure of transmission and distribution lines of many electric utilities. In 1998, an ice storm caused extensive damage to the energy transmission system, resulting in a prolonged power outage for 600,000 customers (an estimated 1.4 million people) in the Northeast and Canada (DeGaetano, 2000). The storm damaged 20 transmission lines, 13,000 utility poles, 100 high-voltage structures, and 5,000 transformers, which cost the two hardest-hit utilities $175 million to repair (DeGaetano, 2000).

Climate change will also affect the amount of energy used by consumers, placing increased pressure on distribution and generation systems during peak periods. Electricity demand relates closely to average monthly temperatures. During periods of high or low temperatures, individuals and businesses consume more energy to heat or cool their homes and businesses. Based on average temperature increases under a higher emissions scenario, it is estimated that the increase in electricity costs from 2005 to 2100 in the Midwest and Western states will be $10.2 billion, with an additional $7.5 billion spent on air conditioners. The Midwest and Western states are projected to see a reduction in the expenditures on natural gas and no change in heating oil, but still see an overall increase in energy costs. Similarly, the Northeast is expected to see a $10.2 billion rise in electricity costs, with an additional $6.2 billion spent on air conditioners. The costs for heating oil and natural gas in this region are expected to decline, but the Northeast may still see an overall increase in energy costs (Ackerman & Stanton, 2008).

Offshore wind turbine. Credit: Jonathan Lilley. Source: NOAA.

In a quantitative assessment of Chicago energy use, the annual aggregate electricity demand is projected to increase 1.3% by 2020 under a higher emissions scenario. By the end of the century, annual electricity demand is projected to rise 2.2% (Hayhoe et al., 2010b).

Case Examples

Energy Efficiency and Sustainability Programs

Building community resilience through efficient use of energy

Changes in temperature and precipitation patterns will alter the demand and production of energy in the Great Lakes region, increasing economic stress on low-income households. To address these issues, many communities around the Great Lakes are implementing energy efficiency and renewable energy programs. The following is a small selection of these local initiatives and should not be viewed as a comprehensive list of energy plans or related initiatives.

Ogdensburg, New York—Energy and Sustainability Program

The City of Ogdensburg was selected as a runner up for the 2010 ICLEI Sustainability Leadership Award for Energy Efficiency Innovation for Small Communities. Ogdensburg City Council adopted the Climate Smart Communities Pledge (see case example on page 73), which set a goal to cut electricity use by 15% by 2015 and to promote climate protection through community planning. The city is installing fine bubble diffuser technology, high efficiency blowers, and methane recapture in the waste water treatment plant which is expected to lower costs and save the city $90,000 per year. The city is also installing fifty kilowatt grid-tied photovoltaic solar panels on the roof of the municipal arena, which is projected to save $8,000 per year.

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Duluth, Minnesota—Duluth Energy Efficiency Program

Initiated in March, 2011, the Duluth Energy Efficiency Program (DEEP) is providing 450 community rebates to help homeowners with high energy bills, ice dams, and old furnaces improve their homes. DEEP created a limited pool of energy rebates ($1.5 million) and prioritizes homes with the highest energy use and targets residential improvements that will save the homeowner the most energy. To identify homes with the greatest energy need, DEEP generates a free energy score based upon actual household energy usage. Households with poor energy scores are then referred to home performance audit programs that provide specific recommendations for improvements as well as potential financing options.

Related Resources: Duluth Energy Efficiency Program. http://duluthenergy.org/

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Cleveland, OH—GreenCityBlueLake Institute Sustainability in Northeast Ohio

The GreenCityBlueLake Institute at the Cleveland Museum of Natural History initiated an energy and climate action planning effort that included taking inventory of the region's greenhouse gas emissions, providing transition plans to reduce emissions and energy use, creating the Cleveland Carbon Fund, and providing toolkits to take effective action to reduce emissions and save energy. The Cleveland Carbon Fund is the world's first open-access community carbon reduction fund. It receives contributions from individuals and organizations, leveraging the resources to fund projects like CFL installation and home weatherization.

Related Resource: GreenCityBlueLake Climate Change. http://www.gcbl.org/climatechange

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ECOSYSTEMS

Key Impacts and Consequences

- Longer summer stratification periods will increase the areas affected by oxygen depletion, which may result in dead zones that kill fish and other aquatic species.
- Increased water temperatures will change the population and distribution of aquatic species, enabling warmer-water species, including invasive species, to colonize new habitats, while reducing habitat for cold-water species.
- Changes in aquatic habitat and population growth will have an economic and operational impact on commercial and recreational fishers as well as aquaculture.
- Changes to air and water temperatures, precipitation, evaporation, and fluctuating lake levels will affect the distribution, productivity, and health of coastal wetlands.
- The increase in invasive species will exacerbate existing ecosystem stresses and compound control costs.

The Great Lakes are the world's largest freshwater ecosystem, and the region is home to a wealth of aquatic and coastal habitats and species. Climate change phenomena, such as higher temperatures, changes in seasonal precipitation, warmer water temperatures, and lower lake levels, are expected to affect the distribution and abundance of species in the region, while altering the goods and services that the ecosystems themselves provide. In some cases, species will thrive but many ecosystems will face challenges to their sustainability. Climate change will allow invasive species to colonize the Great Lakes and compete with native species for resources.

Aquatic Ecosystems

Climate change will alter the structure and dynamics of fish communities around the Great Lakes. Warmer water temperatures coupled with changes in water volume and flow will very likely shift the distribution of fish species while affecting their productivity. This will affect key commercial and recreational species, resulting in potentially severe consequences for the fishing industry and coastal communities that depend on the resources for their livelihood.

Water temperature is an important factor in the distribution and growth of fish in the Great Lakes. Fish living at the northern and southern edges of their range, where there is already greater variability in abundance and growth rates, will be the most affected by changes to the water temperatures (Shuter et al., 2002; Lynch et al., 2010).

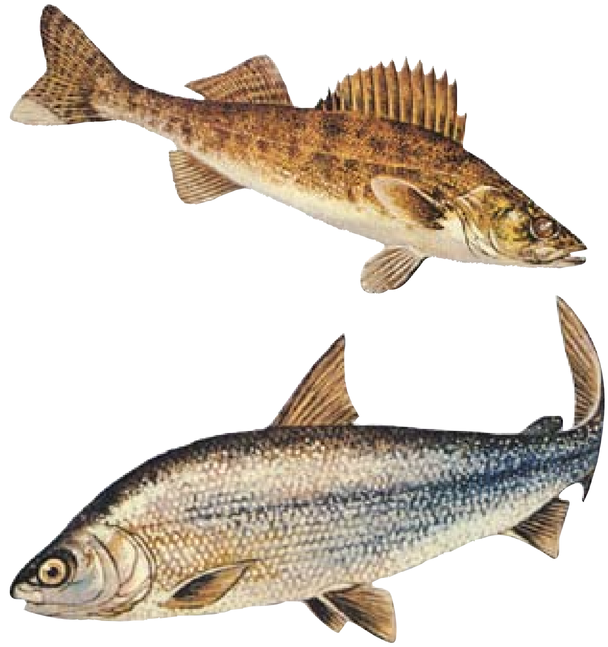
Fish species are grouped by their preferred water temperature into three thermal guilds: cold-water (15°C), cool-water (24°C) and warm-water (28°C). The Great Lakes provide habitat for fish across all three guilds. Optimal habitat area, based on water temperature alone, is expected to expand volumetrically for all three thermal guilds as fish have the opportunity to move northward or deeper into the water column (Lynch et al., 2010). Warmer water temperatures will also increase the metabolic rate of fish, allowing for higher growth and survival rates (Lynch et al., 2010). This is particularly true for cool- and warm-water species living in the Great Lakes. However, increased optimal temperatures alone will not optimize habitat. Other factors such as river hydrology, lake levels, dissolved oxygen levels, and light penetration will also affect future habitat suitability (Jones et al., 2006; Lynch et al., 2010).

While warmer water temperatures will allow many fish species to expand their range, warmer air and water temperatures will also result in an earlier break up of lake ice and a longer summer lake stratification season. When surface water temperatures reach approximately 39°F, a barrier forms between the warmer surface layer and the lower cooler layers and remains until water temperatures drop again in the fall (McCormick & Fahnenstiel, 1999). During this period of stratification, oxygen from the air is unable to circulate below the barrier to lower levels in the lake. This stratification process, while an annual event that typically occurs in summer months, increases the risk of oxygen-poor or oxygen-free zones as the span of time for stratification lengthens, creating dead zones that kill off fish and other aquatic species.

In recent decades, the Great Lakes have begun to experience longer summer stratified seasons, and climate change is expected to increase the stratified seasons even more in the future. Lake Superior, for example, has already seen the onset of summer stratification start a half day earlier every year from 1979 to 2006, an approximate 14-day extension over the 27-year time period (Austin & Colman, 2007). This trend is projected to continue, with the stratified season accelerating and potentially adding between 62 and 90 days in Lake Superior by 2100 (Trumpickas et al., 2009).

Ice cover also plays an important role in aquatic ecosystems. It protects shallow habitats and fish eggs from winter waves and storms. From the 1960s until 2006, the majority of the mildest winters with the lowest average ice cover occurred between 1997 and 2006, with coverage only along the perimeter of the Great Lakes during the warmest years (Assel et al., 2003; Assel, 2005; Karl et al., 2008). Average ice coverage is projected to decrease further in the future (Lofgren et al., 2002; Austin & Colman, 2007), exposing more aquatic habitat to winter waves and storms.

In general, climate change will enhance the production of cool- and warm-water species while possibly reducing the production of cold-water fish populations. Cool-water fish, such as muskie, and warm-water species, like the smallmouth bass and bluegill, will vie to take the place of cold-water populations. On Lake Ontario, climate change will favor the smallmouth bass, a popular recreational fish and native of the southern Great Lakes, over cooler water species like the pike (Casselman, 2002). The bass will expand their northern limit to inhabit shallow embankments and riverine systems, competing with and pressuring other fish communities in nearshore areas (Lynch et al., 2010).



Walleye (top), lake whitefish. Source: NOAA GLERL.

The habitat of walleye, a popular recreational and commercial fish, is already contracting, and this contraction may be exacerbated by climate change. In 2000, walleye accounted for over $9 million in commercial sales on Lake Erie alone (Kinnunen, 2003), but the species relies on cool turbid habitat and is primarily restricted to shallower waters of the Great Lakes (Lester et al., 2004). In recent years, warmer water temperatures and lower lake levels contributed to the contraction of the walleye's habitat in the Bay of Quinte, Lake Ontario (Chu et al., 2005). Evaluations of the future impacts of climate change on Lake Erie walleye populations suggest that warmer lake temperatures will lead to more habitat area particularly in the central and western basins, but lower lake levels would offset these increases and result in a net decline in habitat area (Jones et al., 2006).

Whitefish represent one of the most economically viable commercial species in the Great Lakes. In 2000, whitefish sales topped $10 million on Lake Huron and $6 million on *(Continued on page 52)*

Case Example

Minnesota Department of Natural Resources, a Strategic Conservation Agenda 2009-2013

Translating strategic direction into specific agency action

In December 2010, the Minnesota Department of Natural Resources (MN DNR) published the *Strategic Conservation Agenda 2009-2013* that sets a direction for natural resource management and measures conservation results. The guiding agenda describes three key trends that will shape the state's natural resources and defines a set of strategies to address these challenges. The trends include changes in outdoor recreation participation, changes related to energy and climate, and landscape changes related to growth and development.

Moose. Credit: USDA Forest Service. Source: EPA Great Lakes National Program office.

Along with actions to produce energy on public lands and using energy more efficiently, MN DNR recognizes that mitigating greenhouse gases will not be enough. The agency is tracking carbon storage and sequestration on public lands, while exploring strategies that will boost the climate readiness of natural and working lands.

To meet these challenges, the MN DNR knows that it must manage land and ecosystems in new ways that address the effects of climate change and other pressures on natural systems and measure and monitor the impacts of climate change. Some specific MN DNR actions to date include:

- Started to monitor the biological and chemical changes on two dozen sentinel lakes in Minnesota (SLICE project) to help researchers and managers better understand the interactions between climate, watersheds, lake habitats, and fish populations;
- Hosted a moose summit in 2008 that identified adaptive responses for moose to climate change and provided background for the moose advisory committee report;
- Developed peatland management plans to sequester carbon on state lands;
- Established a climate change adaptation team and other related teams (see below); and
- Conducted a staff survey of knowledge and attitudes about climate change and climate change adaptation strategies.

A key component of the *Strategic Conservation Agenda* is the *Performance and Accountability Report*, which describes the MN DNR's progress towards meeting conservation goals. Of the eighty-three measurable indicators and targets, the MN DNR highlights three key measures that focus on climate change: a carbon inventory on MN DNR-administered land, carbon storage and flows, and percentage of MN DNR management plans with comprehensive strategies for climate change mitigation and adaptation. All three indicators are still in development. Other indicators included in the report, such as the number of buildings removed from floodplains to prevent flood damage, will also increase climate readiness.

To bridge the gap between the direction set forth in the *Strategic Conservation Agenda* and agency action, the MN DNR established the Climate and Renewable Energy Steering Team (CREST) in 2009 with sub-teams for climate change adaptation, carbon sequestration, biofuels, *(Continued on page 51)*

Case Example: MN DNR, a Strategic Conservation Agenda 2009-2013

(Continued from page 50)

and energy efficiency. The CREST developed an internal working document entitled *Climate Change and Renewable Energy: Management Foundations Part I* that describes the science of climate change and renewable energy and provides a common framework to explore management strategies. The working document specified deliverables for each team in 2011. For the adaptation team, these deliverables include the following:

- Disseminate results of a department-wide survey on the knowledge and attitudes of MN DNR staff about climate change and responses to climate change;
- Assist in the development of vulnerability assessments for two major ecosystems while gathering the additional resources for future assessments;
- Build a menu of adaptation strategies that factor in level of uncertainty and risk with low-risk strategies being robust under any climate scenario;
- Host a series of climate change adaptation discussion forums throughout the department, aimed at integrating adaptation strategies into regional and site-level resource management; and
- Seek funds to accelerate climate change adaptation assessments, training, and planning.

Related Resources

- Strategic Conservation Agenda 2009-2013.
  http://files.dnr.state.mn.us/aboutdnr/reports/conservationagenda/conservationagenda.pdf
- Key Measures: Performance and Accountability Report: Minnesota DNR.
  http://www.dnr.state.mn.us/conservationagenda/key_measures.html
- 2008 Moose Summit Presentations.
  http://www.nrri.umn.edu/moose/information/mnmac/MooseSummit2008.html
- 2009 Report to the Minnesota Department of Natural Resources by the Moose Advisory Committee.
  http://www.nrri.umn.edu/moose/information/mnmac/MAC_FINAL_ver_1.01.pdf
- SLICE: Sustaining Lakes In A Changing Environment.
  http://www.dnr.state.mn.us/fisheries/slice/index.html
- Peatland State Natural Area Management Plans.
  http://www.dnr.state.mn.us/input/mgmtplans/peatland/index.html

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Aquatic Ecosystems
(Continued from p. 49)

Lake Michigan (Kinnunen, 2003). The cold-water species, however, will be challenged by warming lake temperatures and lower lake levels. Whitefish are expected to move northward and deeper into the water column, potentially experiencing a loss of habitat at the southern edge of their range but remaining stable over time (Lynch et al., 2010).

In an assessment of climate change on the amount of thermally suitable habitat for lake trout, a cold-water species, it is projected that trout will effectively be eliminated from some lakes in the region. A 4.5°F warming during the next 70 years may reduce brook, rainbow, cutthroat, and brown trout between 25% and 33%. Under these conditions, the optimal thermal habitat for rainbow trout may be reduced by as much as 86% in Pennsylvania, New York, Ohio, Indiana, and Illinois (EPA, 1995).

Invasive species are any species not native to an ecosystem and whose introduction causes economic or environmental harm. Warmer water temperatures will provide the opportunity for aquatic invasive species to colonize the Great Lakes, compounding existing competitive pressures to native species. For example, the cold waters of the Great Lakes limit the expansion of the zebra mussel; however, trends towards warmer waters will very likely allow an expansion of this species (International Joint Commission, 2003).

In an early evaluation of climate warming on invasive species, it is estimated that 19 fish species from the Mississippi or Atlantic coastal

Looking to the Past

Aquatic Invasive Species in the Great Lakes

Invasive species contribute to environmental degradation and loss of native species. They also cause significant economic impacts, including new management costs to the public and private sector. In the early 1980s, the ruffe, a native of Europe and northern Asia, was introduced into the Duluth-Superior Harbor, possibly through ballast water discharged from transatlantic ships (Minnesota Sea Grant, 2009). Since then, the ruffe has expanded its range 150 miles along Lake Superior to Lake Huron (Federal Aquatic Nuisance Species Task Force, 2010). The ruffe caused a decline in 9 native species in the Duluth/Superior Harbor and is expected to result in a $119 million decline in Great Lakes fisheries (Federal Aquatic Nuisance Species Task Force, 2010).

Zebra mussel cluster. Credit: D. Jude, University of Michigan. Source: NOAA GLERL.

Zebra mussels, a native of the Caspian Sea region of Asia, were introduced to the Great Lakes via ballast water from a transoceanic vessel during the 1980s (Minnesota Sea Grant, 2009). Zebra mussels congregate on and clog intake, outflow, and distribution pipes. In 2001, Wisconsin Electric Power Company reported that they were spending $1.2 million per year to control zebra mussels on their Lake Michigan power plants (Wisconsin Department of Natural Resources, 2004). Collectively, Great Lakes users spend $30 million annually to monitor and control the mussels (Federal Aquatic Nuisance Species Task Force, 2010).

Another invasive species that has caused extensive damage to native fish populations is the sea lamprey. This native of the Atlantic Ocean entered the Great Lakes through the Welland Canal in the 1920s (Minnesota Sea Grant, 2009). During the subsequent decades, it was a major factor in the collapse of lake trout populations (Federal Aquatic Nuisance Species Task Force, 2010). The sea lamprey requires a chemical that costs the United States and Canada $12 million annually to control populations (Federal Aquatic Nuisance Species Task Force, 2010).

Case Example

Pennsylvania Aquatic Invasive Species Study

Evaluating risk of aquatic invasive species range expansions in a changing climate

Round goby on rocky bottom. 1998. Credit: D. Jude, University of Michigan. Source: NOAA GLERL.

To understand the effects that the introduction of invasive species may have in a changing climate, Pennsylvania Sea Grant is investigating the vulnerability of Pennsylvania's aquatic ecosystems to these major environmental stressors. The project explores the effects of 3 emissions scenarios on the potential movement of species, identifying the species that have the greatest potential to expand their ranges into Pennsylvania. Using the U.S. Geological Survey's Non-Indigenous Aquatic Species database, project investigators have identified over 50 potential non-indigenous fish, plant, and invertebrate species that could pose a future threat to the state and have compiled natural history information, meteorological data, and climate matching information to determine which non-indigenous species will benefit the most from climate changes experienced by 2099.

The project will generate maps, suitability indices, and other tools that will be combined into case studies for the most threatening species. These case studies will provide a framework that can be used to develop prevention strategies and prioritize species of greatest risk to Pennsylvania.

Related Resources

- Pennsylvania Sea Grant Climate Change Projects. http://pserie.psu.edu/seagrant/extension/projects.htm

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basins would invade Lakes Ontario, Erie, and Michigan, and 8 fish species would invade Lakes Huron and Superior by the end of the century (Mandrak, 1989).

Aquaculture is a growing industry in the region, and it is expected to continue to rise in the future. In 2002, the gross value of the commercial aquaculture industry was over $78 million, and it produced approximately 50 species of fish (Ladwig, 2002). In Ontario, commercial aquaculture clusters in the North Channel of Lake Huron and Georgian Bay and produces approximately 7 million pounds of rainbow trout annually, contributing more than $38.2 million to Ontario's yearly economy (Ontario Ministry of Natural Resources, 2011). This potentially thriving industry will be impacted by changing climate conditions as lake levels fluctuate, storm events increase in frequency and intensity, and water temperatures rise.

For more information on climate change adaptation measures, *Adapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for coastal and marine ecosystem management starting on page 85. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf

Case Example

Chicago Wilderness Climate Action Plan for Nature

Building a regional alliance to maintain biodiversity and enhance the climate resilience of ecosystems

In the mid-1990s, 34 founding members, working on ecosystem biodiversity issues in the Chicago region, came together and formed the Chicago Wilderness (CW) alliance. In 1999, CW developed the *Biodiversity Recovery Plan* (BRP), identifying systematic threats to aquatic and terrestrial ecosystems and recommending actions alliance members could take to manage ecosystems on protected lands.

Recognizing that climate change could put their conservation efforts at risk, the CW Executive Council established climate change as one of four long-term strategic initiatives, and created a Climate Change Task Force. The task force released *Climate Change and Regional Biodiversity: A Preliminary Assessment and Recommendations for Chicago Wilderness Member Organizations* in 2008. This preliminary assessment provided the basis for the *Climate Action Plan for Nature* that the council adopted in 2010.

The *Climate Action Plan for Nature* provides an integrated framework for the CW alliance to mitigate the future impacts of climate change, adapt to those impacts that are inevitable, and engage the CW community in action. The plan recommends modifying existing planning and programs to assess the vulnerability of priority terrestrial and aquatic conservation targets; promote and maintain larger, connected landscapes for biodiversity resiliency; integrate stormwater management policy with information on climate change; and develop monitoring programs to evaluate adaptation strategies. While still in the early stages, CW is working on a number of projects to achieve these actions.

Climate Clinics

Since launching the *Climate Action Plan for Nature*, the Climate Change Task Force established a Climate Clinic program with the following objectives: increase the capacity of CW members to practice conservation amidst the threat of climate change, encourage members to take first steps in mitigation and adaptation, encourage partnerships between members to build communities of knowledge, and discuss climatic changes occurring in the region. The clinics work to help members better understand and communicate climate change information in the region, while describing the strategies outlined in the *Climate Action Plan for Nature*. Adaptation topics introduce how to make conservation strategies climate-ready, assess species vulnerability, reduce the impacts of other ecological stressors that constrain native species, and assist migration.

To date, the task force along with the Field Museum, The Nature Conservancy, and the City of Chicago has hosted five clinics: two for land managers, two for educators, and one for communities in Chicago working to implement adaptation strategies through the *Chicago Climate Action Plan* and the *Climate Action Plan for Nature*. The modules and tools created for the Climate Clinics will be made available to CW members.

Biodiversity Recovery Plan

Published in 1999, the CW BRP is a blueprint for saving and restoring the rare natural communities of the Chicago region. Originally intended as a living document, the CW alliance is now revising the BRP with climate change in mind. The revision will consider the impacts of climate change and other ecological stressors that could constrain the ability of native species to persist. Best management approaches and restoration strategies will be updated to incorporate climate change.

Assessing Vulnerability

The CW Climate Change Task Force also created a working group to assess the vulnerability of priority aquatic and terrestrial ecosystems to climate change. Working with the U.S. Fish *(Continued on page 55)*

Case Example: Chicago Wilderness Climate Action Plan for Nature

(Continued from page 54)

and Wildlife Service, Notre Dame Collaboratory, The Nature Conservancy, the Field Museum, and other members, the task force is modeling community and species vulnerability. This information will help illustrate the exposure of key species to climatic changes, while looking at a species' natural history, distribution, and landscape circumstances to understand the effect on population size and range.

Indiana Dunes National Lakeshore. Credit: M. Woodbridge Williams, National Parks Service. Source: NOAA GLERL.

Green Infrastructure Vision

Beginning in 2004, CW created a comprehensive plan for the preservation and conservation of 1.8 million acres of land in the greater Chicago region called the Green Infrastructure Vision (GIV). The GIV paints a regional-scale picture of protected and natural areas that support biodiversity and provide habitat for aquatic and terrestrial species. The Chicago Metropolitan Agency for Planning used the GIV as the foundation for its *GOTO 2040 Regional Comprehensive Plan*.

Efforts are currently underway to review the GIV in response to the recommendations outlined in the *Climate Action Plan for Nature*. A working group is reviewing the strategic initiatives outlined in the GIV to assess whether they are climate-ready, promote ecosystem-based adaptation, and communicate the benefits of adaptation. The group is also assessing the carbon sequestration potential of existing protected lands as well as the additional areas proposed in the GIV. The tools developed by the working group will be made available to land managers through the Climate Clinic program, allowing them to estimate carbon sequestration of their lands.

Related Resources

- Chicago Wilderness Climate Action Plan for Nature.
  http://www.chicagowilderness.org/pdf/CAPN_Brochure-FINAL_singlepages_WEB_6.21.10.pdf
- Chicago Wilderness Biodiversity Recovery Plan.
  http://www.chicagowilderness.org/pdf/biodiversity_recovery_plan.pdf
- Chicago Wilderness Green Infrastructure Vision.
  http://www.chicagowilderness.org/pdf/Green_Infrastructure_Vision_Final_Report.pdf

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Coastal Wetlands

Coastal wetlands support rich plant, bird, and fish populations along the Great Lakes, providing a unique transition zone between aquatic and terrestrial ecosystems and a variety of important ecosystem services. Changes to air and water temperatures, precipitation, and fluctuating lake levels will affect the distribution, productivity, and health of these coastal wetlands.

Climate change in the Great Lakes is projected to bring warmer temperatures and longer dry spells between precipitation events, particularly during the late spring to fall months. It is anticipated that wetlands that are more dependent on precipitation, such as bogs, will be more vulnerable to climate change than those species reliant on groundwater. In the southern and western portions of the region where less rainfall is expected, wetland loss is expected to occur (International Joint Commission, 2003).

A warmer summer season with fluctuating lake levels will threaten some types of coastal wetlands, while providing the opportunity for different types to colonize new territory and thrive. Higher water levels eliminate trees, shrubs, and other emergent vegetation. Lower water levels result in seed germination and growth of many species. Wetland plants have unique characteristics that enable them to grow at different elevations and under different moisture conditions. As water levels change, the abundance of vegetative communities adjusts with some species dying back while others take their place. During low water years, new land areas are uncovered. Sedges, grasses, and shrubs replace emergent vegetation in areas once covered by water, while submerged wetlands give way to emergent vegetation. As water levels rise, the process reverses. Emergent vegetation gives way to submerged wetlands, and emergent vegetation moves into areas previously colonized by sedges, grasses, and shrubs (Wilcox and Nichols, 2008; Mortsch et al., 2006; Trexel-Knoll & Francko, n.d.).

Invasive species, already a challenge for coastal wetlands, will become an even greater challenge with climate change. *(Continued on page 58)*

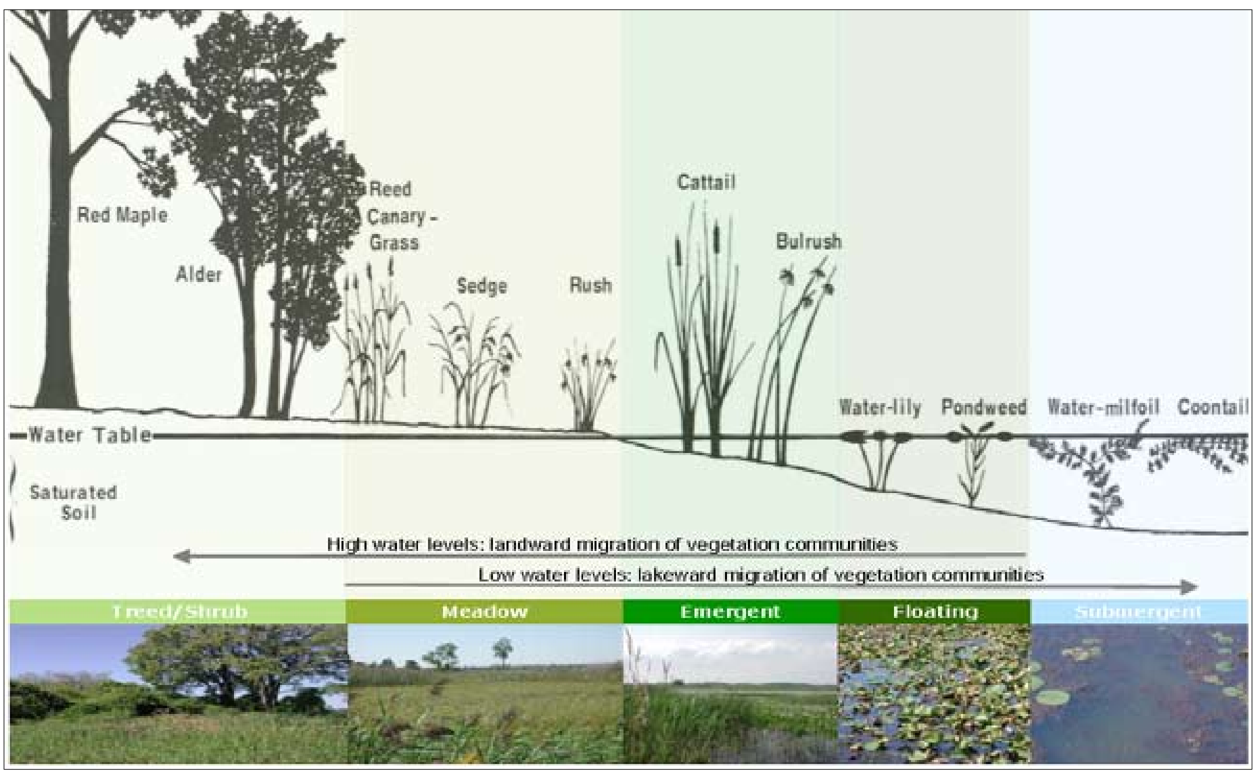

Figure 7: Wetland vegetation community development along water table continuum (adapted from Bolsenga and Herdendorf 1993). Source: Mortsch et al., 2006.

Case Example

Huron Pines Invasive Species Removal

Engaging property owners to manage wetland vegetation

Working in partnership with organizations and agencies through a grant from the Michigan Coastal Management Program, the Huron Pines Resource Conservation and Development Council (Huron Pines) published the *Northeast Michigan Coastal Stewardship Project* report in 2009 to protect and enhance coastal resources. The report recommended that Huron Pines take the lead on addressing invasive species removal such as *phragmites australis* before they became a major disruption in the region, particularly given that climate change could improve the conditions for *phragmites australis* colonization. In northeast Michigan, invasive species populations are small—ideal for finding and treating quickly, at low cost to the public.

From the start, Huron Pines focused on developing a long-term, sustainable program for *phragmites australis* removal by facilitating a public-private partnership. In 2009, Huron Pines created a Cooperative Weed Management Area to define the geographic area, focus on particular invasive species, and coordinate efforts in an official partnership. Partners include the U.S. Fish & Wildlife Service, U.S. Forest Service, Michigan Department of Natural Resources & Environment (MI DNRE), The Nature Conservancy, Natural Resources Conservation Service, and many local governments and interest groups. In addition, Huron Pines brought both local government officials and property owners together and worked to educate and engage them about invasive species removal. The organization developed an early detection and rapid response system, tying together an aerial inventory conducted by the MI DNRE with on-the-ground surveys. The invasive species removal program started with 6 properties in 2009, scaling up to 80 properties treated and over 200 landowners reached in 2010.

The program mixes funding from federal and state grants as part of a cost-share program with individual property owners. Huron Pines contributes 75% of the funding, and landowners must sign an agreement to maintain the beach for 10 years. Huron Pines estimates initial treatment costs at approximately $1,000 per acre.

Not only has the program enabled Huron Pines to discuss and eradicate invasive species with property owners, but it has provided an opportunity for staff to discuss emergent, wetland vegetation and climate change with the landowners. Many landowners were not aware that rare and endangered species inhabit the beaches of northeast Michigan, and those species need habitat that is being taken over by invasive species. Rather than remove all vegetation from the beach, the staff have convinced many owners to maintain native wetland vegetation as a means to increase the long-term resilience of Michigan's coast.

Related Resources

- Northeast Michigan Coastal Stewardship Project.
  http://www.huronpines.org/upload/File/CoastalPlan-073109.pdf
- Northeast Michigan Cooperative Weed Management Plan.
  http://www.huronpines.org/upload/File/CWMA_signed.pdf
- Invasive Species Fact Sheet: Phragmites.
  http://www.huronpines.org/upload/File/Invasives%20-%20Phragmites.pdf

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Coastal Wetlands

(Continued from page 56)

Lower lake levels and warmer air temperatures will provide the opportunity for invasive species such as *phragmites australi*s (the common reed) to colonize shoreline areas. This was the case along Long Point, Lake Erie in Ohio, where *phragmites australis* increased significantly from 1995-1999 during a period of lower water levels and higher temperatures (Wilcox et al., 2003). Similarly, after a period of declining water levels in 2000, *phragmites australis* expanded into the wetlands, particularly the emergent vegetation areas, at Old Women Creek National Estuarine Research Reserve on Lake Erie in Ohio, requiring intensive management to control (Trexel-Knoll & Francko, n.d.).

A change in water levels will alter the type and quality of plants growing in the wetlands, transforming the biodiversity of species that live, breed, forage, and seek refuge in Great Lakes wetlands. Because many species in the wetlands are part of the larger food web in the Great Lakes, changes to wetland plant communities will affect ecosystems throughout the region (Trexel-Knoll & Francko, n.d.). An increase in extreme events, such as heavy precipitation or droughts, may affect the ability of certain species of amphibians and birds to breed and mature. Some species, like the yellow-headed blackbird, require specific wetland habitat that is already shrinking (Kling et al., 2003). Climate change will potentially compound the stress already faced by such species.

Climate change will also affect the functioning of wetlands in the Great Lakes region. Wetlands act as an interface between land and water, filtering nutrients, pollutants, and other sediments before they enter the lakes. It is anticipated that changes to the movement of water through wetlands because of altered precipitation and runoff patterns will affect flushing, sedimentation, and nutrient input (Hall & Stuntz, 2007). For instance, decreased runoff, particularly during the summer, will lessen the movement of materials such as human and agricultural waste from uplands into wetlands (Kling et al., 2003). This will have positive effects for the lakes, as wetlands will be required to filter less waste and less waste moves into the lakes. At the same time, climate change is expected to affect the rate of material decomposition in wetlands, potentially reducing the ability of wetlands to assimilate nutrients and waste.

Wetland plants. Credit: D. O'Keefe, Michigan Sea Grant. Source: NOAA GLERL.

While all wetland communities have the ability to adapt to climate change, specific impacts and associated responses will be influenced by the speed of climatic changes (Mortsch et al., 2006). The more quickly changes occur in lake levels, precipitation patterns, and temperatures, the greater the impacts on wetland communities as their adaptive capacities are exceeded. Trees in wetlands, for example, are slow to respond to climate and environmental changes, potentially resulting in negative impacts on tree species (International Joint Commission, 2003).

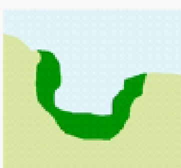
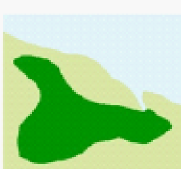
To estimate the potential impact of lower water levels on wetland communities along Lakes Erie and Ontario, wetland distribution and abundance were estimated for different climate change water level scenarios and compared to historic vegetation coverage. It is expected that wetland distribution and abundance will adjust, however, altering the habitat for bird and fish communities (Mortsch et al., 2006).

Under scenario conditions where lake levels fall modestly, it is projected that there will only be small changes in wetland communities. These conditions will become preferable for trees, shrubs, and meadow types of vegetation, allowing these communities to expand along the upper margins of the wetland. Unsurprisingly, these conditions will become favorable to nesting birds that are associated with this habitat (Mortsch et al., 2006).

Under scenarios where lake levels decline more, it is anticipated that wetlands will transition to drier vegetation communities such as treed areas, shrubs, and meadow marshes. These types of wetland communities will not be as productive as more diverse wetland systems, and are not expected to be as favorable to certain birds and fish. In general, a warmer, drier future with low water levels will be worse for wetlands, birds, and fish. Under these conditions, it is expected that there will be significant shifts to species distribution and abundance, relative to historic conditions (Mortsch et al., 2006).

For more information on climate change adaptation measures, A*dapting to Climate Change: A Planning Guide for State Coastal Managers* includes measures for coastal and marine ecosystem management starting on page 85. http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf

Table 8: Summary of Impact of Climate change on Great Lakes Coastal Wetlands

Wetland Site Type (study site examples)	**Major Characteristics**	**Main Impacts of Climate Change**
Lacustrine (e.g. Long Point, Turkey Point, Presqu'ile, South Bay) 	• open to and most affected by Great Lakes, including water level fluctuations, nearshore currents, seiches, and ice scour • wetlands in open and protected bays • varying degrees of organic sediment and vegetation development • bathymetry, gentle to steep slope, dependent on degree of protection from lake effects and geology (ice scour and seiches)	• potential for more exposure to extreme winter storms and less ice protection • aquatic, submergent and emergent vegetation may migrate lakeward with lower levels if suitable sediment, slope, seed banks exist • drier vegetation communities (sedges, grasses and shrubs) expand in current wetland • warmer temperatures may result in vegetation community shifting over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g. corridor, birds) • cumulative stresses may encourage spread of invasive species • loss and contamination from increased demands for dredging • mud flats exposed • less interspersion
Riverine (e.g. Dunnville, Lynde Creek, Hay Bay, Lake St. Clair wetlands) 	• occur near the mouth of tributaries to and connecting channels of the Great Lakes • water quality, inflow and sediment loading are strongly influenced by runoff from the watershed but also affected by the lake • often protected from waves • types include: open to the lake, along connecting channels, behind barrier bars and in delta • steep river bank and river channel, with flat flood plain	• more variable river flooding regimes affect wetland which can lessened influence of lake levels • more sedimentation from more extreme precipitation events causing more erosion upstream; vegetation covered with sediments and fish and wildlife habitat adversely affected • lower flows may increase pollutant concentrations • warmer water temperatures decrease dissolved oxygen • may be able to migrate toward river-mouth as levels decline but dependent on sediment, slope and seed bank • warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance • cumulative stresses may encourage spread of invasive species
Barrier-Enclosed 	• occur behind a barrier beach formed by coastal processes • gradual slope but barrier beach is an obstruction to downslope vegetation movement once a particular water level threshold has been reached • generally protected from waves but may be lake-connected during high water periods (or extreme storms) • varying connectivity to lake and influence by lake water levels • includes barrier beach and swale complexes between relic beach ridges with decreasing lake level influence as move landward • more prevalent in lower lakes where more coastal sediments are available	• unable to shift lakeward with lower lake levels so gradual drying of wetland; dominated by meadow, shrub and tree communities with associated shift in diversity, productivity and habitat value • drying may increase risk of fire • shifting coastal processes may alter barrier or re-form a lakeward one • warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g. corridor, birds) • warmer water temperatures decrease dissolved oxygen • cumulative stresses may encourage spread of invasive species • wetland area decreases

(Mortsch and Koshida 1996; Mortsch 1998; IPCC 2001b; Hebb 2003; Kling *et al.* 2003; Wilcox 2004; Albert *et al.* 2005)

Source: Mortsch et al., 2006

Case Example

Huron River Watershed Council Climate Change Education

Creating science and policy tools to educate and engage the public

Founded in 1965, the Huron River Watershed Council (HRWC) is a non-profit council that aims to protect, rehabilitate, and sustain the ecological and cultural communities of the Huron River ecosystem by bridging the gap between communities, residents, and business. HRWC serves as a resource for local governments and citizens seeking solutions to critical issues facing the Huron River, providing scientific data and policy tools to influence decisions.

In winter 2009, HRWC published a report for the Huron River that sought to educate communities and the public about the impacts of climate change on the region's freshwater. The report outlined the effects of climate change on Michigan, sections of the watershed, and fish populations, while describing solutions to increase the resilience of the watershed to changing conditions. These solutions included compact development, protection of natural areas, green infrastructure, and water conservation; the report highlighted Michigan cities that had begun implementing these practices.

Huron River. Source: NOAA GLERL.

Many HRWC programs already address challenges exacerbated by climate change and help to increase the resiliency of the Huron River. HRWC coordinates a volunteer stream monitoring program, works with communities to implement a model stream buffer and wetland ordinance, helps neighborhoods implement green infrastructure, provides assistance for watershed planning, conducts natural area mapping, educates and engages the public with resources on green infrastructure and water quality, and participates with other organizations to urge federal action on climate change.

Since anywhere from 10%-20% of total energy use goes towards treating, moving, and heating water, the Masco Foundation and HRWC are launching a 3-year project to develop and disseminate a home "Saving Water, Saving Energy" toolkit. HRWC will document how saving water works as a strategy to mitigate climate change in the watershed and educate consumers about water-efficient plumbing products, water saving habits and practices and how saving water translates into energy savings, less greenhouse gas emissions, and doing something to combat climate change.

Related Resources

- Huron River Report: Climate Change Addition.
  http://www.hrwc.org/wp-content/uploads/2009/07/FINALWinter2009.pdf
- Wetland Protection: A Model Ordinance.
  http://www.hrwc.org/the-watershed/watershed-protection/wetland-protection/
- Model Ordinance: Riparian Buffer.
  http://www.hrwc.org/wp-content/uploads/2009/11/HRWC_riparianbuffer_model_ordinance.pdf

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RECREATION AND TOURISM

Key Impacts and Consequences

- Park visitation is expected to increase in the future, particularly during the spring and fall seasons.
- Warmer air and water temperatures will extend the swimming season at Great Lakes beaches, but extreme events could lead to more beach closures.
- Declining lake levels will negatively affect recreational boaters and anglers.
- Warmer temperatures, reduced snowfall, and less lake ice will reduce or eliminate the season for ice fishing and snowmobiling.

Travel and tourism brought over $85 billion in revenue to the Great Lakes region in 1999 (Kling et al., 2003), providing a huge economic driver as well as cultural 'way of life' for the Great Lakes region. Climate change will affect land-based, water-based, and snow-based recreation and tourism sectors, altering the length and quality of the seasons and modifying the resources that recreation depends upon.

Land-Based Recreation and Tourism

Land-based recreation constitutes one of the most important categories of recreation in North America and includes activities such as camping, hunting, and beach and park visitation. Under changing climatic conditions, park visitations are expected to increase in the future, particularly during the spring and fall seasons. While this tourism increase will benefit the park system in general, additional pressure will be placed on the management of natural resources within the parks, particularly during sensitive periods like spring breeding.

Sleeping Bear Point hiking trail, Lake Michigan. Credit: National Park Service. Source: NOAA GLERL.

To estimate the potential impact of climate change on park tourism through the end of the century, the change in average park visitation for several Great Lakes national, state/provincial, and local parks was estimated for different climate change scenarios and compared to existing attendance levels. Park visitation at Cuyahoga Valley (Ohio), Point Pelee (Ontario), and Pukasaw (Ontario) National Parks and five provincial parks in Ontario is expected to rise from 9%-23% by 2020 and from 16%-72% by 2080 (Dawson & Scott, 2010). At Cuyahoga Valley National Park along Lake Erie, the number of annual visitors is projected to grow from an historic average of 3.3 million to between 3.4 and 3.5 million visitors in 2020 (Hyslop, 2007). By the end of the century, it is projected that Cuyahoga Valley visitors will range from 3.5 to 3.8 million, an increase of up to 22% (Hyslop, 2007).

Many national, state/provincial, and local parks provide public access to beaches and shorelines along the Great Lakes. Public beaches provide a variety of recreational activities for residents and visitors and will be affected by a changing climate. Warmer air and water temperatures will extend beach use overall and the number of swimming days at Great Lakes beaches.

Sauble Beach on Lake Huron in Ontario is projected to see a significant rise in beach use and days in the swimming season. The current beach season at Sauble Beach is approximately 152 days with 59 swimming days per year. As early as

Sand castle building in Duluth, Minnesota, Lake Superior. Credit: Minnesota Sea Grant. Source: EPA Great Lakes National Program office.

2020, the beach use season is projected to increase by 9 to 21 days for a lower and higher emissions scenarios respectively, adding between 15 and 40 days to the swimming season. By the end of the century, beach use is expected to rise between 30 and 87 days, and the swimming season is estimated to be extended between 29 and 99 days – more than doubling the swimming season (Scott & Jones, 2010).

Likewise, the season length for the Toronto beaches on Lake Ontario currently averages 167 days for beach use and 86 for swimming. By 2020, the season length for beach use is projected to increase between 19 and 39 days, while the swimming season is expected to rise between 16 and 36 days. By 2080, the beach use season is estimated to increase between 20 and 85 days, and the swimming season is anticipated to rise between 27 to 86 days (Scott & Jones, 2010).

It is important to note that heat waves, high heat days, and potential increases in nearshore algal blooms may offset some of the economic and quality of life benefits associated with extended beach use days and swimming seasons. Similarly, more frequent heavy precipitation events are expected to lead to more runoff and CSOs. These events may result in increased exposure for tourists and residents to waterborne diseases and result in more beach closures.

Bird and wildlife watching also represents an important social and economic driver in the region. Climate change will likely affect the distribution of species and alter the timing and extent of migration. This is certain to affect the bird and wildlife watching tourism sector.

Water-Based Recreation and Tourism

A changing climate will present both opportunities and challenges for recreational boating and fishing. Earlier ice melt and warmer temperatures will extend the boating and fishing season. However, these changes will alter the distribution and productivity of fish communities, impacting recreational anglers. Additionally, lower lake levels may offset the benefits of a longer season, causing negative economic impacts to the boating and fishing industries.

The U.S. Army Corps of Engineers estimated there are 911,000 recreational boaters in the eight Great Lakes states who spend $2.36 billion annually on trips and $1.44 billion annually on boats and equipment (U.S. Army Corps of Engineers, 2008). This spending generates 60,000 jobs and over $1.75 billion in personal income (U.S. Army Corps of Engineers, 2008). A 2001 survey of Lake Ontario and St. Lawrence River boaters found that fluctuating water levels had a significant impact on boater activity during the previous record low water years (McCullough Associates & Diane Mackie Associates, 2002).

Sailing the Apostle Islands, Lake Superior. Credit: Wisconsin Division of Tourism. Source: EPA Great Lakes National Program office.

To assess the economic impact of lower lake levels on recreational boating on the New York side of Lake Ontario, mean economic value for boat launch ramp users, private dock users, and marina and yacht club users was collected and evaluated against potential water level elevations (Figure 9). If the water levels stay above approximately 245.5 feet, boaters may use the marinas and yacht clubs whenever they wish, and they would not be affected by water levels. As water levels decline, some boats would be caught in their slips, resulting in fewer boating days and lost economic value. Losses in net economic value begin to occur when Lake Ontario water levels drop below 245.5 feet. If water levels drop to 244 feet for the entire month of August, approximately $8 million in net economic benefits would be lost (Connelly et al., 2007).

By the end of the century, average Lake Ontario water levels will likely decline for a higher emissions scenario. The average lake level decline is estimated to be 1.28 feet (Angel & Kunkel, 2010). Since the long-term mean lake level is approximately 245.5 feet (NOAA, 2011), it's possible that water levels will fall below 244 feet by the end of the century, with intra-annual and inter-decadal variations falling significantly lower.

Climate change may also affect recreational fishing in the Great Lakes by changing the distribution and abundance of popular species. Optimal habitat area, based on water temperature, is expected to expand for Great Lakes fish, and warmer water temperatures will allow for higher growth and survival rates (Lynch et al., 2010). Other factors such as river hydrology, lake levels, dissolved oxygen levels, and light penetration will also affect future habitat suitability, potentially decreasing the available area for recreational species (Jones et al., 2006; Lynch et al., 2010).

For more information about the impacts and consequences of climate change on fish communities, please see the Aquatic Ecosystem section on page 48.

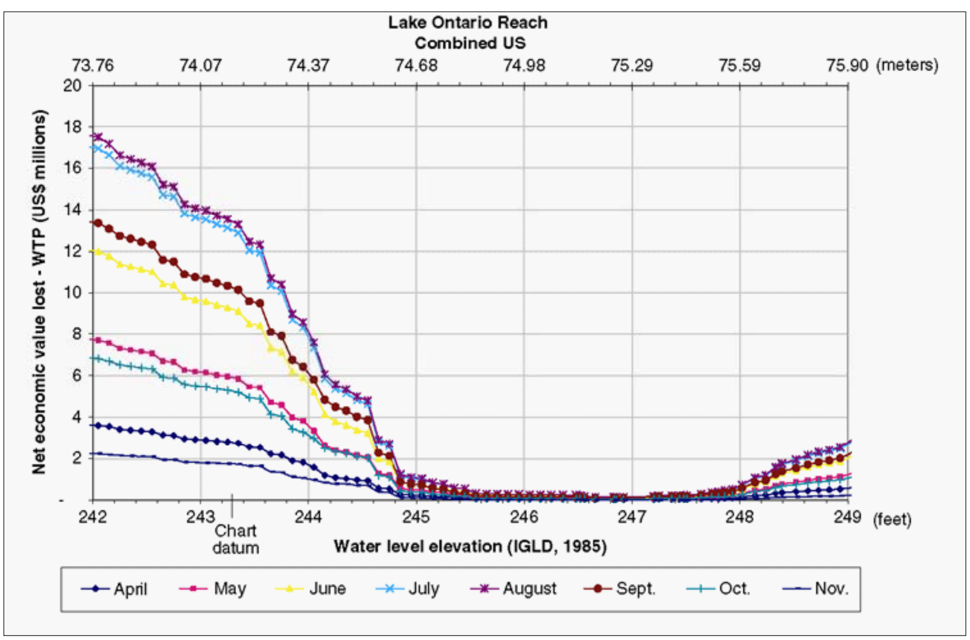


Figure 9: Stage-damage curves using net economic values lost by month for all U.S. Lake Ontario reach users. Source: Connelly et al., 2007.

Winter Recreation and Tourism

Warmer temperatures, reduced snowfall, and less lake ice will negatively impact winter recreation and cultural practices in the Great Lakes region. Ice fishing is particularly susceptible to climate change. For safety reasons, ice thickness must range from 5.9-9.8 inches, but warmer lake waters and earlier ice melts will reduce the length of time that lake ice remains this thick.

Ice fishing, Lake Michigan. Credit: Jack Deo, Michigan Travel Bureau. Source: EPA Great Lakes National Program office.

Like ice fishing, snowmobiling is highly sensitive to climate variability. Snowmobiling relies on natural snowfall accumulation, which is projected to decline. As winter temperatures increase this century, the average length of the snowmobiling season and the area where snowmobiling can occur will also decrease.

Compared to the average season length between 1961 and 1990, snowmobiling seasons are projected to be shorter for lower and higher emission scenarios, as the southern edge of the snowmobiling region moves north (Scott et al., 2008; McBoyle at al., 2007).

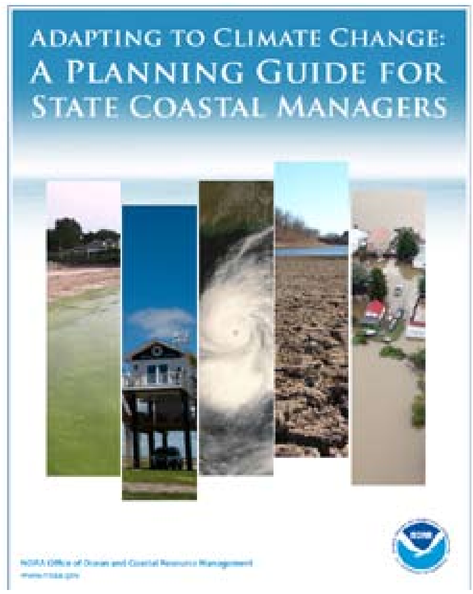
- The baseline snowmobiling season length for a study area in western New York State was 22 days, and it is expected to decline 68% under both low and high emissions scenarios between 2010 and 2039. By century's end, the season length is projected to fall between 85% and 92% (Scott et al., 2008).
- In north central New York State, it is expected that the baseline snowmobiling season length of 94 days will fall between 15% and 16% by 2039, declining an estimated 39% to 78% by the end of the century (Scott et al., 2008).
- In three southern Ontario sites (two adjacent to Lake Huron, one adjacent to Lake Superior), snowmobiling seasons are projected to decrease between 24% and 68% by 2020. By 2080, it is anticipated that the snowmobiling season will be reduced between 38% and 100% (McBoyle at al., 2007).

These results suggest a less hospitable environment for snowmobiling by century's end, or much sooner as the economic investment and risk of harm may not be worth the benefit derived from the minimal number of days with sufficient snow depth.

CHAPTER 4: CLIMATE CHANGE ADAPTATION PLANNING

NOAA provides planning guidance and training to the nation's coastal resource management community to help build their capacity to prepare for climate change and plan for adaptation. This chapter describes *Adapting to Climate Change: A Planning Guide for State Coastal Managers*, a guidance document released by NOAA's Office of Ocean and Coastal Resource Management in 2010, and a series of NOAA training programs available to professionals in the Great Lakes region. This chapter also includes examples of state, regional, and local government taking steps to plan for and adapt to the potential impacts of climate change.

ADAPTING TO CLIMATE CHANGE: A PLANNING GUIDE FOR STATE COASTAL MANAGERS



To help U.S. state and territorial (state) coastal managers develop and implement adaptation plans to reduce the impacts and consequences of climate change and climate variability, NOAA published *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. The planning guide includes science-based information on climate change and steps for setting up a planning process, assessing vulnerability, devising a strategy, and implementing the plan. It is based on needs assessments and a wide variety of resources specific to climate change, sustainability, resilience, general hazard mitigation, and natural resource management. These resources are noted throughout the planning guide.

Establish the Planning Process

The NOAA planning guide presents a common framework for the adaptation planning process that follows the steps of a traditional planning process and stresses the importance of stakeholder participation and building flexibility into the process to allow for the accommodation of new data, perceptions, realizations, and vulnerabilities. The primary tasks associated with climate change adaptation planning as suggested in the guide are as follows:

Stakeholder engagement. Credit: Chesapeake NEMO. Source: NOAA.

- Establish the Planning Process—scope planning project, assess resource needs and availability, assemble the planning team, and educate and engage stakeholders.

- Assess Vulnerability—identify climate change phenomena, impacts, and consequences; assess physical exposure to the impacts; consider adaptive capacities; develop scenarios, and summarize vulnerability; and prioritize focus areas.
- Create an Adaptation Strategy—set goals, identify actions, select and prioritize actions, and write action plans.
- Design a Plan Implementation and Maintenance Process—adopt and implement the plan, mainstream actions into other programs and planning processes, monitor and communicate progress, and update the plan.

For more information on the planning process, visit http://coastalmanagement.noaa.gov/climate/docs/ch3planningprocess.pdf.

Case Example

Michigan and Wisconsin Memorandum of Understanding

Establishing an interstate partnership to achieve common goals to combat climate change

The Michigan Department of Natural Resources and Environment and the Wisconsin Department of Natural Resources signed a memorandum of understanding (MOU) in 2010 that provides a framework for the state agencies to establish common goals to jointly pursue research, planning, and implementation for climate change adaptation and mitigation. The states agreed to exchange information and data; enhance coordination and cooperation along state borders, in watersheds, and in the Great Lakes; identify and communicate opportunities for joint participation; share research and technical expertise; propose action plans to address climate change adaptation; and explore potential funding options.

The states agreed to appoint representatives who will meet at least twice each year to determine common objectives and discuss options to minimize the consequences of future climate change. The states hope that the agreement will be a template for cooperation with other states, tribes, and local governments in the region. There are already tentative discussions with Minnesota as the three states share a common forest and coastal resource area.

A tangible result of the MOU has been the collaboration between the Michigan Climate Coalition (MCC) and the Wisconsin Initiative on Climate Change Impacts (WICCI). The MCC hopes to design an organizational framework to address climate change and related issues that is modeled on the WICCI. Most recently, the MCC has been working with WICCI representatives to explore how the WICCI was formed, what the organizational structure is like, and what the next steps for the MCC may be.

Related Resources

- Memorandum of Understanding. http://mi.gov/documents/deq/dnre-climatechange-MI-WI_MOU_Climate_Change_332449_7.pdf
- Michigan Climate Coalition. http://www.espp.msu.edu/climatechange/michigan_climate_coalition.php/
- Wisconsin's Changing Climate: Impacts and Adaptation. http://www.wicci.wisc.edu/publications.php

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Vulnerability Assessment

To help those engaged in adaptation planning identify areas or specific assets most vulnerable to climate change, and the phenomena and associated impacts that could cause the greatest losses, the NOAA planning guide presents the key steps and considerations for conducting a climate change vulnerability assessment in the coastal zone. These steps include collecting existing information about phenomena, impacts, consequences, physical characteristics, exposure, and adaptive capacities (to set the context) and using the information to fine tune projections, simulate climate change, and summarize vulnerability. The planning guide stresses using the best available data and not putting off adaptation planning efforts because of lack of information or issues of uncertainty.

For more information on vulnerability assessments, visit http://coastalmanagement.noaa.gov/climate/docs/ch4vulnerabilityassessment.pdf.

Case Example

Great Lakes Integrated Sciences and Assessment Center

Working with cities and watershed council to define climate change data needs and provide broad access to downscaled climate data

Launched in the fall of 2010, the Great Lakes Integrated Sciences and Assessment Center (GLISA) seeks to contribute to the long-term sustainability of the region in the face of a changing climate and to improve the utility of scientific knowledge to decision making. To meet these goals, GLISA is pursuing three programs: an assessment of stakeholder networks, compilation and evaluation of downscaled models, and funding research projects.

GLISA is identifying and assessing downscaled models for the Great Lakes region. The GLISA team is also collaborating with key stakeholders to understand their data needs. By working with cities like Ann Arbor and Grand Rapids, as well as organizations like the Huron River Watershed Council, GLISA hopes to develop an online resource that will allow a wide variety of decision makers to satisfy their climate change data needs.

GLISA researchers are also reviewing assessments conducted in the region to identify common themes regarding stakeholder needs and research priorities. These past reports are being used to map stakeholder networks and better understand how climate change related information and data have flowed among groups in the region.

GLISA is a collaboration of the University of Michigan, Michigan State University, and the Ohio State University. The project is supported by a 5-year grant from NOAA and is part of NOAA's Regional Integrated Sciences & Assessments program.

Related Resources

- Great Lakes Regional Integrated Sciences and Assessments Center. http://www.glisa.umich.edu/index.php

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Adaptation Strategy

After describing the vulnerability assessment process, the NOAA planning guide outlines the basic steps for creating an adaptation strategy. This process includes establishing goals based on the vulnerability assessment and identifying, evaluating, selecting, and prioritizing actions that can help meet them.

The majority of this chapter describes measures that can be taken to reduce the impacts of climate change on the coast. Since many of the impacts and consequences of climate change are not new, simply exacerbated or accelerated, actions to reduce them already exist and are being implemented outside the context of climate change. The planning guide illustrates how familiar actions can also be used to support climate change adaptation. Following a discussion of planning, law making, and regulating, potential measures are organized into categories that describe their primary purpose, including impact identification and assessment, awareness and assistance, growth and development management, loss reduction, shoreline management, coastal and marine ecosystem management, and water resource management and protection.

For more information on creating an adaptation strategy, visit http://coastalmanagement.noaa.gov/climate/docs/ch5adaptationstrategy.pdf.

Case Example

Wisconsin Initiative on Climate Change Impacts

Creating an informal, science-based strategy to address the impacts of climate change

The Wisconsin Initiative on Climate Change Impacts (WICCI) represents a unique and innovative process for developing a statewide climate change adaptation strategy. The WICCI relies on an informal, bottom-up approach to engage scientists, researchers, and management agencies in understanding the impacts of climate change on natural resources and communities across the state and develop strategies to make them more resilient to climate change.

The WICCI was formed in the fall of 2007 as a collaboration between the University of Wisconsin-Madison's Nelson Institute for Environmental Studies and the Wisconsin Department of Natural Resources (WI DNR). An ad-hoc group of scientists from both entities developed the structure of the WICCI—an organization that grew to include representatives from other state and federal agencies, several University of Wisconsin system schools, tribal organizations, businesses, and non-profit groups.

An initial step in forming the WICCI was the establishment of a Science Council. The Science Council is co-chaired by a representative from University of Wisconsin-Madison and the WI DNR, and it includes individuals from the University of Wisconsin system as well as state and federal agencies. Members of the Science Council represent a diverse array of fields from natural resource management to public health. While the Science Council contributes to many aspects of the WICCI, its primary functions are to organize and coordinate the individual sector and geographic working groups (WGs) and keep the WICCI process moving forward, recently adding new responsibilities to fund raise and develop regional partnerships.

The WGs evolved out of a voluntary process. New WGs arose as individual champions stepped forward or as the Science Council identified a need and recruited expert individuals to lead research and planning efforts. In all, fifteen WGs have formed so far, covering vital sectors to the state impacted by climatic changes, such as water resources, wildlife, and agriculture, and *(Continued on page 69)*

Case Example: Wisconsin Initiative on Climate Change Impacts
(Continued from page 68)

geographic regions like Green Bay and Milwaukee. The geographic approach, in particular, is unique among U.S. states that have developed a climate change adaptation strategy to date. One of the first WGs formed was the Climate WG. The Climate WG assessed historical climate trends and made future climate projections based on downscaled results of global climate models. This information became the foundation for the sector and geographic assessments conducted by the other WGs.

As a result of the WG process, the WICCI released its first comprehensive report in 2011, *Wisconsin's Changing Climate: Impacts and Adaptation*, to serve as a resource for decision makers and stakeholders across the state as they began to take strategic action to make people, natural resources, and infrastructure more resilient to climate change. The report summarizes historic and future climate changes and describes the impacts of a changing climate on five sectors: water resources, natural habitats and biodiversity, agriculture and soil resources, coastal resources, and people and their environment. The document contains a chapter for each sector, describing key impacts, cases studies, and specific adaptation strategies. More importantly, the working papers and research from each WG is available for resource managers and stakeholders who require more specific data and information to make informed decisions.

Since releasing the WICCI report, a Communications and Outreach Group has been working to frame and communicate the information in the report, sharing key findings with the media. They are also working with K-12 public educators to incorporate climate change into school curricula and discussing findings with county conservationists. Moving forward, the Outreach Group in conjunction with individual WG leaders will work with institutions like the University of Wisconsin Extension program and county conservation agencies to increase the awareness of climate change impacts at the local level.

Developing the WICCI report yielded several important lessons learned from the self-organizing, bottom-up process. Although the champion approach provided leadership for an individual WG, this resulted in gaps in the planning process. Some WGs, such as cold-water fisheries, produced robust technical analysis and adaptation options, while other topic areas, like transportation infrastructure, received little to no attention. WGs also focused on areas where they had the most expertise in a relatively short amount of time. For example, the forestry WG analyzed biological issues but did not address economic considerations. The Science Council and WICCI report acknowledged these gaps, noting that planning for climate change is an iterative and on-going process, specifically because it is voluntary and bottom-up and tied to existing research, issues, and funding. The WICCI is continuing to identify new WGs and topics, including an economic WG and a community sustainability WG, to address these concerns in subsequent analyses and reports.

Related Resources

- The Wisconsin Initiative on Climate Change Impacts. http://www.wicci.wisc.edu/
- Wisconsin's Changing Climate: Impacts and Adaptation. http://www.wicci.wisc.edu/publications.php

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Plan Implementation and Maintenance

The final chapter of the planning guide discusses adopting and implementing the plan; integrating adaptation into other programs and plans; tracking, evaluating, and communicating plan progress; and updating the plan, which are all critical to the overall success of the planning effort. It also includes a brief discussion of federal, state, and local sources of funding for climate change adaptation.

For more information on plan implementation and maintenance, visit http://coastalmanagement.noaa.gov/climate/docs/ch6implement_maintenance.pdf.

Case Example

Chicago Climate Action Plan

Preparing a city for a changing climate

At the request of the mayor, a multi-stakeholder Chicago Climate Task Force was created and initiated a planning process to assess the potential impacts of climate change on the city's economy and environment and recommend actions for the city to minimize those impacts. Grounded in rigorous analysis of climate change impacts and a corporate risk assessment for municipal operations and public facilities, the planning process engaged a variety of stakeholders, evaluated a significant number of adaptive actions, and built a case for future action. Recommendations were incorporated into the 2008 *Chicago Climate Action Plan* (CCAP), and this plan formed a roadmap for Chicago to tackle the challenges presented by climate change.

To understand the impacts of climate change on Chicago, Lake Michigan, and the region as a whole, a team of scientists used atmosphere and ocean general circulation models and statistical downscaling to assess impacts at the regional scale for both higher and lower emissions scenarios. Some of the top climate change impacts for Chicago were: an increasing number of days over 95°F, warmer winters and much warmer summers, periods of enhanced precipitation and dryness when least needed, changes in Great Lakes water levels, and shifting plant hardiness zones. Along with the Chicago climate change impacts report, *Climate Change and Chicago: Projections and Potential Impacts*, research results have been cited in numerous sources including the *Journal of Great Lakes Research*.

Next, Chicago assessed the economic risk that climate change poses to municipal operations and public facilities. Using the climate change impacts identified by the research teams, the impact of climate change on city budgets under a higher and lower emissions scenario was compared to a baseline scenario. *The Corporate Risk Case Study for Chicago* found that under a lower emissions scenario, budgets could be expected to increase by $690 million by 2100. Under a higher emissions scenario, the case study estimated that budgets would increase by $2.54 billion, thereby indicating significant future cost implications.

After completing the impacts analysis and the risk assessment, the city prioritized the potential environmental and economic impacts associated with future climate changes and compiled a list of potential adaptation options in the *Chicago Area Climate Change Quick Guide: Adapting to the Physical Impacts of Climate Change*. The guide provides a simplified approach to assessing and comparing risks across sectors and climate change impacts; combining a measure of likelihood of a predicted climate change impact occurring with a measure of the magnitude of the consequence. The results of the simplified risk assessment allow planners and decision makers to understand the most significant vulnerabilities. The quick guide also includes an initial list of approximately 150 adaptation 'tactics' or actions for heat, extreme precipitation, ecosystems, and infrastructure. This list was narrowed down based on benefit-cost analysis, timing, and barriers to implementation and resulted in a list of 15 priority tactics, with 39 corresponding adaptive actions that city departments have begun to take. *(Continued on page 71)*

Case Example: Chicago Climate Action Plan

(Continued from page 70)

Chicago Climate Action Plan Adaptation Advisory Group

To aid departments and agencies, an Adaptation Advisory Group was convened to provide high-level guidance for Chicago's ongoing adaptation implementation efforts. Chaired by the Chicago Department of Environment, the group includes representatives from the University of Illinois, New York City, Toronto, the Great Lakes and St. Lawrence Cities Initiative, Kresge Foundation, MWH Global, the Hispanic Housing Development Corporation, Gade Environmental Group, ArcelorMittal, and other city and state government agencies. The group is working to evaluate metrics to measure adaptation success, evaluate existing responses, prioritize future actions, provide input on adaptation communications, and identify existing resources and funding.

Department and Agency Work Plans

As outlined in the CCAP, the city expects individual departments and agencies to lead by example. To date, 22 departments and agencies have developed their own climate action work plans. These work plans identify specific initiatives that each agency has committed to and define clear and actionable goals. Over 100 staff members are contributing to climate action efforts, with over 450 initiatives (both mitigation and adaptation) directed towards the goals outlined in the CCAP. Progress on these initiatives is coordinated and tracked quarterly.

Related Resources

- Chicago Climate Action Plan.
  http://www.chicagoclimateaction.org/filebin/pdf/finalreport/CCAPREPORTFINALv2.pdf
- Chicago Climate Change Impacts Report Summary.
  http://www.chicagoclimateaction.org/filebin/pdf/report/Chicago_Climate_Impacts_Report.pdf
- Preparing for Changing Climate: The Chicago Climate Action Plan's Adaptation Strategy.
  http://www.chicagoclimateaction.org/filebin/pdf/
  JGLRArticleonTheChicagoClimateActionPlansAdaptationStrategy.pdf
- Corporate Risk Case Study: City of Chicago Climate Change Task Force.
  http://www.chicagoclimateaction.org/filebin/pdf/report/CorporateRisk2008August5.pdf
- Chicago Area Climate Change Quick Guide: Adapting to the Physical Impacts of Climate Change.
  http://www.chicagoclimateaction.org/filebin/pdf/ADAPTATION4POST2.pdf
- Lessons Learned: Creating the Chicago Climate Action Plan.
  http://www.chicagoclimateaction.org/filebin/pdf/LessonsLearned.pdf

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Resources and Appendices

A key component of the NOAA planning guide is the extensive list of resources for coastal climate change adaptation planning and implementation. Key resources are noted at the end of each chapter and are compiled into a single reference document. The planning guide and the key resources reference document are available at http://coastalmanagement.noaa.gov/climate/adaptation.html.

In addition, the planning guide has three appendices. These appendices provide information about existing federal programs that may provide funding for climate change adaptation planning and project implementation, federal laws and executive orders that support climate change adaptation, and how climate change may affect the different regions of the United States, including the Northeast and the Midwest.

The guide also promotes the NOAA Coastal Services Center's Coastal Climate Adaptation web site as a place to learn more about climate change adaptation. Cataloged resources include adaptation and action plans, case studies and strategies, climate change communication, climate change science and impacts, guidance

Case Example

Ann Arbor Systems Planning Unit

Reorganizing staff to better address sustainability and climate change issues

The structure and organization of government agencies and departments influences the process of planning; it may aid or hinder the ability of staff to comprehensively address issues such as climate change. Climate change often requires staff to collaborate outside their typical policy areas to effectively address challenges. This collaboration enables organizations to capitalize on overlapping goals, reduce duplication, and effectively leverage limited resources.

To this end, the City of Ann Arbor, Michigan, reorganized 14 departments into 4 service areas and used this opportunity to create the Systems Planning Unit with a focus on strategic planning and long-term asset management. This group brings together individuals with skills in energy efficiency, environment/sustainability, recycling/compost, stormwater, floodplain management, non-motorized transportation, water quality, geographic information systems, infrastructure modeling, engineering/capital improvement investments, brownfield redevelopment, emergency management, urban planning, urban forestry, and public engagement. The Systems Planning Unit fosters better interactions among these key disciplines and coordination across service areas.

The Systems Planning Unit worked with staff to create 12 core metrics for the capital improvements planning (CIP) process, including two that further sustainability goals. For each project, staff must identify 1) how each project furthers one or more of the city's 10 environmental goals and 2) how the project saves energy or increases the use of renewable energy. This new process embeds sustainability planning, including climate change planning, within municipal operations. The city expects to integrate climate adaptation into the next CIP process planned for 2012.

Related Resources

- Systems Planning Unit.
  http://www.a2gov.org/government/publicservices/systems_planning/Pages/SystemsPlanning.aspx

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and guidebooks, outreach materials, policies and legislation, risk and vulnerability assessments, stakeholder engagement, and training and workshop materials. Access the site at http://collaborate.csc.noaa.gov/climateadaptation/.

Case Example

New York State Climate Smart Communities

Providing guidance and tools to incentivize communities to take climate action

Launched in 2009, the voluntary Climate Smart Communities (CSC) program provides guidance and technical support to local governments to lower greenhouse gas emissions and adapt to the unavoidable impacts of climate change. The Department of Environmental Conservation is currently compiling a *Climate Smart Communities Guide to Local Action* that provides examples of possible actions, instructions for implementing actions, and case studies of CSC member accomplishments. CSC members also receive notification of state and federal assistance programs, support for efficiency conservation, an advantage in some state assistance programs, and statewide recognition. The state anticipates providing direct technical support to jurisdictions that have become CSCs in developing greenhouse gas emissions inventories and climate action plans during 2011.

To become a Climate Smart Community, a local government must adopt a model pledge by legislative resolution that establishes a local climate program and appoint a climate coordinator to gain public support. The model pledge advises communities to identify climate change risks to government facilities and functions and factor them into long-term investments and decision making.

As of mid-2011, 90 communities in New York have signed onto the CSC Pledge, including eleven in Great Lakes and St. Lawrence counties: City of Ogdensburg, Village of Norwood, Village of West Carthage, City of Oswego, County of Oswego, City of Rochester, Town of Irondequoit, Town of Lewiston, Town of Porter, Town of Royalton, and Town of Somerset.

Related Resources

- New York Department of Environmental Conservation's Climate Smart Communities. http://www.dec.ny.gov/energy/50845.html
- Climate Smart Communities: A Guide for Local Officials. http://www.dec.ny.gov/docs/administration_pdf/cscgd.pdf
- Text for the Climate Smart Communities Resolution: Model Pledge for Community Adoption. http://www.dec.ny.gov/energy/65494.html

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NOAA GREAT LAKES CLIMATE ADAPTATION TRAININGS

The Great Lakes region is projected to experience significant coastal impacts due to global climate change that are different than impacts projected for ocean coasts. NOAA provides training to the nation's coastal resource management community to build their capacity to prepare for climate change and plan for adaptation at local geographic scales. Three options for training are available for audiences with differing levels of climate literacy, technical expertise, and adaptation planning capacity.

Climate Ready Great Lakes

Purpose: *Climate Ready Great Lakes* is designed to assist Great Lakes coastal communities in preparing for possible effects of climate change. Introductory training modules are centered on three primary climate topics:

- Climate Change Impacts - provides information on climate change in the Great Lakes based on peer-reviewed science
- Adaptation Planning - describes the steps involved in developing a plan for climate adaptation
- Climate Change Adaptation Tools – highlights decision-support tools for adaptation planning

Primary Audiences: Communities or regional organizations that are beginning to consider how to plan for climate change adaptation and have not committed significant resources to the initiative. The tools module may also be adaptable to community planners at later stages in the planning process.

Length: Each of the modules is two-to-four hours in length. Modules are flexible and adaptable for different settings and can be updated to include future research and tools that increase the body of information useful for local decision-makers. As such, they can be delivered as a whole or in customized pieces as needed by the intended audience.

Trainers: Sea Grant Program Extension staff, USDA Extension staff, Coastal Management Program staff, and other trained outreach professionals who work with local community decision-makers in the Great Lakes region.

For additional information or to discuss the possibility of holding this training in your area, e-mail rochelle.sturtevant@noaa.gov.

Planning for Climate Change

Purpose: The one day *Planning for Climate Change* workshop introduces local and state planners to climate change, as well as the planning processes and actions that can help communities prepare for climate change impacts. Course materials, including presentations, handouts, and lessons learned, are customized for regions and states.

After completing this course, participants will be able to:

- Recognize basic climate science principles;
- Identify expected climate change impacts both locally and globally;
- List the fundamentals of adapting to climate change, including the planning process and conducting a risk and vulnerability assessment;
- Recognize the need to engage all stakeholders in climate change preparedness activities;
- Indicate the barriers to adaptation and recognize some tools to overcome them; and
- Identify existing regulations and how they impact their state's ability to prepare for climate change.

Primary Audiences: Professionals involved in local and state planning and decision making related to land use, public health, stormwater, emergency preparedness, and natural resource management that are interested in enhancing their community or agency's capacity to plan for climate change. Organizational commitment to climate planning is not required for participation.

Length: One day. Six hours of certification maintenance credits for this course have been approved by the American Institute of Certified Planners. Registration fees will vary by location.

Trainers: Workshops will be planned and coordinated by the Old Woman Creek and Lake Superior National Estuarine Research Reserves in partnership with the NOAA Coastal Services Center, Great Lakes Sea Grant and Coastal Management Programs, Great Lakes Regional Water Program, and other regional partners. The course will be offered in Cleveland, Ohio; Green Bay, Wisconsin; and Duluth, Minnesota. The workshops are planned to be held in late summer/early fall of 2011.

For additional information or to discuss the possibility of holding a similar workshop in your area, e-mail heather.elmer@dnr.state.oh.us.

Climate Change Adaptation for Coastal Communities

Purpose: The *Climate Change Adaptation for Coastal Communities* training course provides resource managers, planners, and program administrators with the fundamental concepts, latest information, and necessary skills to proactively address impacts of climate change in coastal communities. Participants will identify an issue relevant to their work, and throughout the course will be completing documents that outline the steps, information needs, and actions they want to consider when integrating climate adaptation into existing efforts.

After completing this course, participants will be able to:

- Recognize the human and natural influences on climate and climate's influence on coastal communities;
- Discuss the relationship between government, nongovernment, and markets as they relate to climate adaptation;
- Examine methods for conducting hazard, vulnerability, and risk assessment by locating and interpreting available data and information and addressing uncertainty in decision making;
- Evaluate the strengths and weaknesses of adaptation options and how to integrate them across issues; and
- Apply recent climate communication research concepts and findings to develop a message that effectively communicates with their target population about their chosen climate issue.

Primary Audiences: Local and state coastal resource managers whose communities have the capacity for and have made an initial commitment (time, resources) to engage in climate change adaptation planning.

Length: This course is a 3 ½ day, seven-module curriculum. Twenty hours of certification maintenance credits are being sought from the American Institute of Certified Planners. Registration fees will vary by location.

Trainers: Workshops will be planned and coordinated by the NOAA Coastal Services Center in partnership with the Old Woman Creek and Lake Superior National Estuarine Research Reserves, Great Lakes Sea Grant and Coastal Management Programs, Great Lakes Regional Water Program, and other regional partners. The workshops are planned to be held in late summer/early fall of 2011.

For additional information or to discuss the possibility of hosting this training in your area, e-mail csc.training.request@noaa.gov.

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APPENDIX

INTERVIEW QUESTIONS FOR STATE COASTAL MANAGERS

This section shows the script used during interviews with state coastal managers.

1. Please describe your current role and activities specific to climate change adaptation.

2. In which Great Lakes Basin do you work?

3. What are the primary impacts of climate change that most concern your state?
   a. If multiple basins: Please describe any variation in climate change impacts between basins.
   b. Please describe any variation in climate change impacts within the basin.

4. Does your state have a strategy to address these impacts?
   a. Please describe any policies or programs that attempt to minimize these impacts.
   b. Do you consider any of these policies or programs to be exemplary?

5. Does your state have specific goals or priorities with respect to climate change?
   a. If so, do they mesh with other agency goals and priorities?

6. Please describe the regulatory tools your state leverages to minimize the impacts of climate change.
   a. Which tools are most effective? And why?
   b. Which tools are the least effective? And why?

7. Does your state have a formal or informal policy for protecting shorelines against coastal erosion?

8. Does your state require local governments to create comprehensive plans?
   a. If so, are local governments required to include coastal or hazard preparedness elements?
   b. Are local governments required to consider the impacts of climate change?
   c. Do you consider any of these plans to be exemplary?
   d. What role does your state have in the administration, development or implementation of these plans?

9. According to climate scenarios analyzed by the US Global Change Research Program, water levels in the Great Lakes are projected to fall by the end of the century. How will your state approach land uncovered by lower lake levels?
   a. Do the appropriate regulations exist for your state to do this?
   b. If not, what rules or laws need to be modified?

10. Climate change is projected to affect, and in some cases is already affecting, the distribution and productivity of aquatic and wetland ecosystems in the Great Lakes Region. What ecosystem impacts most concern your state?
   a. Please describe any policies or programs your state has implemented to manage these current or projected impacts.
   b. Do you consider any of these policies or programs to be exemplary?

11. According to climate scenarios analyzed by the US Global Change Research Program, winter and spring precipitation is expected to become more intense, potentially overwhelming aging drainage systems and water treatment plants. Does your state and local governments have the necessary policies and programs to manage stormwater and/or Great Lakes water quality under these changing conditions?
   a. Do you consider any of these policies or programs to be exemplary?
   b. Are there examples of regional or local governments in coastal areas with exceptional policies for

managing stormwater and/or water quality?

12. Does a changing climate affect the way your state manages Areas of Concern (AOC) now or in the future?
    a. If so, please describe how you envision climate change will affect the management of the AOCs?
    b. Does your state have the necessary tools and resources to manage AOCs under future climatic conditions?

13. Please describe any tools or resources your organization offers to regional and local government in coastal areas to minimize the impacts of climate change.

14. Are there examples of regional and local governments in coastal areas addressing climate change within your state?
    a. Please describe these regional and local government policies and programs.
    b. Do you consider any to be exemplary?
    c. Do you recommend we speak with any particular individual?

15. Is your state or organization collecting data that could be used to assess climate change impacts on your state's coast? What are the near-term data gaps that need to be assessed? Long-term?

16. What resources would be most helpful to your state as you begin to plan for and adapt to a changing climate? What would be your top 2 or 3 priority resources?

17. How will your state measure and monitor the effectiveness of climate change adaptation strategies?

18. Have you seen, or had a chance to review the NOAA Adapting to Climate Change: A Planning Guide for State Coastal Managers publication?
    a. If so, what suggestions do you have to make the Great Lakes Adaptation Planning Guide Supplement to the "Adapting to Climate Change: A Planning Guide for State Coastal Managers" most useful to you?

19. What else would you like the research team to know?

Great Lakes RESTORATION

http://coastalmanagement.noaa.gov/climate/adaptation.html

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