

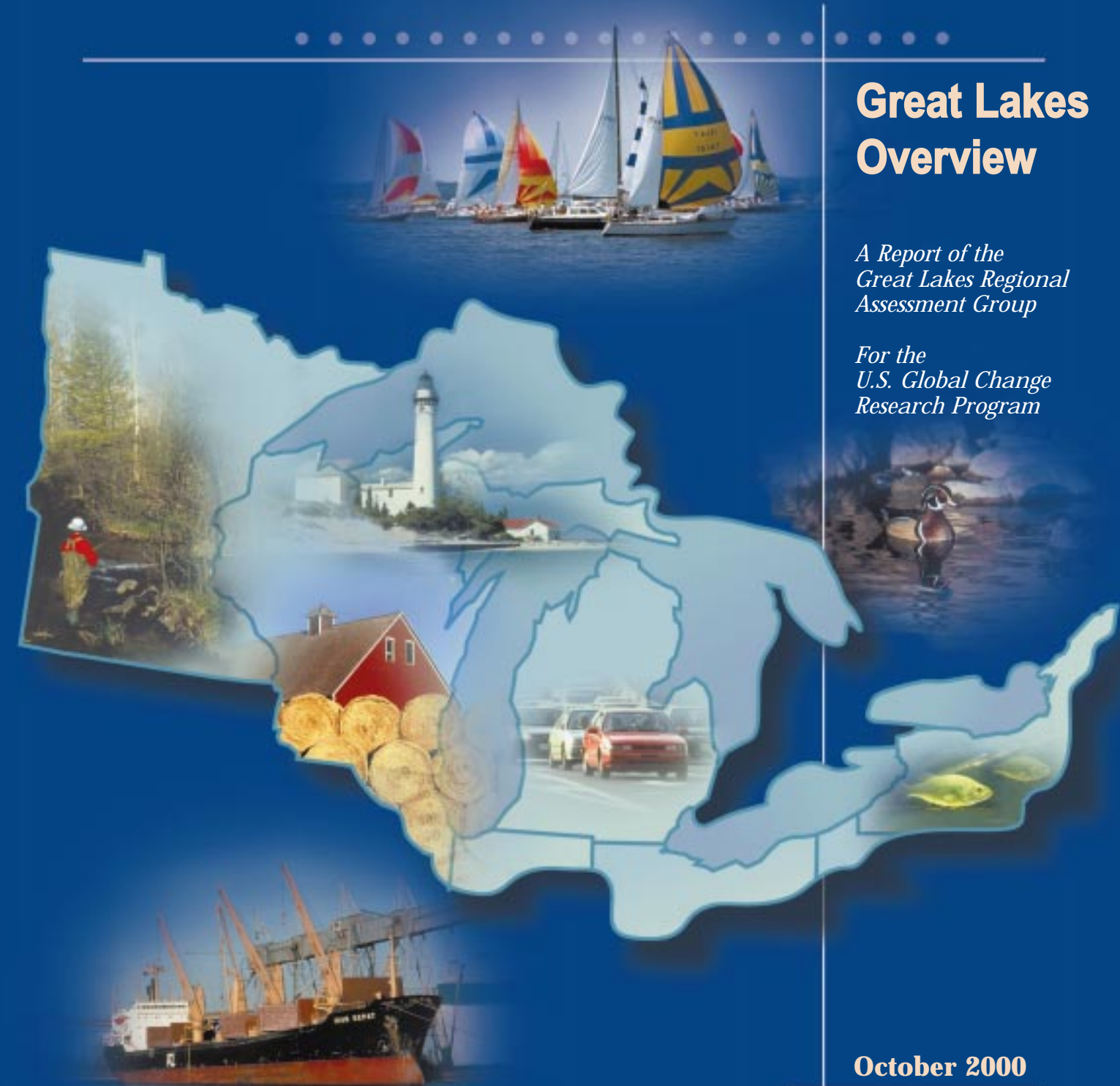
PREPARING FOR A CHANGING CLIMATE

*The Potential Consequences
of Climate Variability and Change*

Great Lakes Overview

*A Report of the
Great Lakes Regional
Assessment Group*

*For the
U.S. Global Change
Research Program*



October 2000

PREPARING FOR A CHANGING CLIMATE • GREAT LAKES

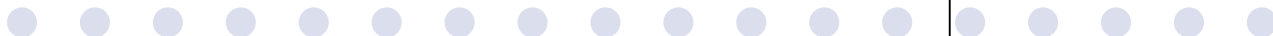
October 2000

Great Lakes Regional Assessment

University of Michigan
Atmospheric, Oceanic and Space Sciences Department
Ann Arbor, Michigan 48109-2143
ISBN 0-9705619-0-3

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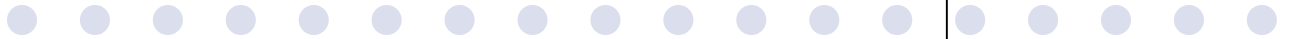
This publication was developed under Cooperative Agreement No. CR 827236-01-0 awarded by the US Environmental Protection Agency to the University of Michigan. The EPA as well as dozens of other scientists from other academic and research institutions reviewed the document and made comments and suggestions in order to improve the scientific analyses and technical accuracy of the statements in the document. Although these comments were incorporated, the views expressed in this document are solely those of the University of Michigan and EPA does not endorse any products or commercial services mentioned in this publication.

ISBN 0-9705619-0-3

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PREPARING FOR A CHANGING CLIMATE

The Potential Consequences of Climate Variability and Change



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Sponsored by

The U.S. Environmental Protection Agency
Office of Research and Development
Global Change Research Program
(Cooperative Agreement No. CR 827236-01-0)
with John Furlow as Project Officer

Great Lakes

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Research Program*

*An Investment in Science
for the Nation's Future*

October 2000

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About this Publication

This report summarizes the methods, findings, and recommendations from the Great Lakes Regional Assessment Team regarding the potential impacts of future climate change and variability in the Great Lakes region. It complements the national overview report that is being prepared by the National Assessment Synthesis Team (NAST) as part of the National Assessment of Climate Change. The report is intended for use by federal, state, and local government officials and by people in their roles as US citizens, employees, and residents of the community. The report focuses on the years 2030 and 2090. These two times occur approximately 30 years before and after the time when atmospheric carbon dioxide is expected to have doubled from its current value.

While there have been many national assessments and even a few Great Lakes Regional Assessments in the recent past, our assessment includes several key features that make it unique:

- 1) *substantial stakeholder participation*. Stakeholder participation during our regional workshop in May 1998 led to decisions to assess impacts on certain aspects of agriculture, forestry, water resources, ecosystems, and people's well-being.
- 2) *interdisciplinary approach*. Our assessment involved a true integrated team effort and significant collaboration, using the best science available. This proved to be challenging given existing time constraints and the fact that the team consisted of more than 40 faculty, research associates, graduate and undergraduate assistants, and external collaborators, from around the region (see Appendix B for a list of the full team). Communication among team members was imperative to ensure that results across sectors were consistent. This was especially challenging given the fact that most sector-assessment teams used different models that required specifically formatted input.
- 3) *recent GCM output*. Our assessment required us to use recent output from general circulation models (GCMs) that accounted for aerosols and for steady increases (as opposed to instantaneous doubling) in atmospheric carbon dioxide.
- 4) *comparisons to previous results*. Our assessment includes, wherever possible, comparisons between results from previous assessments and ours. The purpose of the comparisons is primarily to highlight some of our latest results to demonstrate that (a lot of) new information was obtained – rather than just reformatting existing information.

Enthusiastic teamwork has accomplished an astounding amount of work on a very compressed schedule. I would like to thank each Great Lakes Regional Assessment Team member for his or her work. The interaction between researchers and regional stakeholders in terms of their comments on earlier drafts has resulted in many modifications and improvements. On behalf of the Great Lakes Regional Assessment Team, I would like to thank the regional stakeholders for their careful reviews, their insights, and their thoughtful responses. I would also like to thank Grabhorn Studio for the cover design. I would especially like to thank the US Environmental Protection Agency (EPA) for their financial support and EPA Project Officer John Furlow for his periodic guidance.

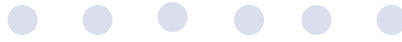
Finally, I owe the greatest thanks to Ms. Jeanne Bisanz, the Regional Coordinator of our Great Lakes Assessment Team, whose untiring efforts have led to the timely completion of this report.

Additional information is available on the Great Lakes Regional Assessment web site <http://glra.engin.umich.edu>. More technical information about the Great Lakes Regional Assessment will appear in a special issue of *Journal of Great Lakes Research*, that will be printed in Spring 2001. Even more detail will be in the revised longer report (current version is Sousounis et al. 2000b), which is expected to be on the Great Lakes Regional Assessment web site by October 2000.

This report is being printed for broad review. We welcome feedback (e-mail: sousou@umich.edu; phone: 734-936-0488; fax: 734-764-5137; mail: Dr. Peter J. Sousounis, AOSS Department, University of Michigan, Ann Arbor, MI 48109-2143).

Peter J. Sousounis, Director
Great Lakes Regional Assessment Team

EXECUTIVE SUMMARY



Part of a National Assessment

The US Global Change Research Program (USGCRP) is conducting its first National Assessment of the Potential Consequences of Climate Variability and Climate Change. This National Assessment is motivated by recently documented evidence of warming across much of the United States, and a concern about what future climate change may bring to the Nation in terms of water resources, ecology, coastlines, and human health to name a few. The Assessment has three major components including 16 regional assessments, of which the Great Lakes Regional Assessment is one. The results from the regional assessments will be combined with the results from five *sectoral analyses* (Agriculture, Forests, Human Health, Water, and Coastal Areas/Marine Resources) to create a *National Overview*.

Goals of the Great Lakes Regional Assessment

A team consisting of approximately thirty investigators from around the Great Lakes region was assembled to assess the potential impacts of climate change and variability in the region. The goals of the Great Lakes Regional Assessment were to identify:

How key sectors in the region are sensitive to climate-change-related and non-climate-change related stresses

What information previous assessments can provide relating impacts of climate change on key sectors in the region

What the potential impacts of climate change on key sectors in the region will be based on climate change scenarios from the latest general circulation model simulations

How individuals and communities can take advantage of opportunities to reduce vulnerabilities resulting from climate change and variability

What additional information and research are needed to improve decision making related to impacts from climate change and variability.

The specific sectors that were chosen for assessment were motivated in part by findings from a regional workshop that was held at the University of Michigan in May 1998. The assessments are challenging because of uncertainties in climate change projections, socioeconomic change projections, and because of a lack of information and models that link changes based on these projections across sectors.

The Great Lakes Region - Now and in the Future

The Great Lakes region, for the purposes of this assessment, consists of the Great Lakes drainage basin, and all of Minnesota, and Wisconsin. The population of this region has increased from roughly 10 million in 1900 to over 40 million currently. Lumbering, farming, and mining played a big role in the development of the region during the last half of the 19th century. Steel manufacturing and the automobile industry dominated the last half of the 20th century.

The importance of the region is related strongly to the fact that the Great Lakes constitute the single largest source of fresh water in the world (except for the polar ice caps). The Lakes themselves are a linchpin for drinking water, hydroelectric power, commercial shipping, and recreation to name but a few. Additionally, the Lakes and the shorelines provide various habitats for numerous plant and animal species.

The unique location of this region – halfway between the equator and North Pole within a large continental land mass and colocated with the largest lakes in the world – gives it a unique climate. This climate is characterized by warm summers, cold winters, and significant precipitation year-round. Additionally, the Great Lakes have a considerable influence on the sub-regional climates around the lakeshores, particularly in winter in the form of lake-effect snowstorms in winter. These storms contribute up to 50% of the annual snowfall totals in areas around the lakes (e.g., the snowbelts).

Climate scenarios from two General Circulation Models: the Canadian Climate Center Model (CGCM1) and the United Kingdom Hadley Center Model (HadCM2) suggest that the climate will be 2–4°C (3.6–7.2°F) warmer and about 25% wetter by the end of the 21st century. There will also be fewer cold air outbreaks and less lake-effect snow in winter – especially around the southern lakes (Erie and Ontario). Such changes in snow-storm frequency would decrease the cost of snow removal and decrease the frequency of transportation disruptions. However, there would be adverse consequences to the winter recreational industry in southern portions of the Great Lakes. Summertime heat waves and heavy precipitation events will become more frequent.

Key Findings

This regional assessment focused on how a warming climate might impact levels of the Great Lakes, streamflow, aquatic and terrestrial ecosystems, agriculture, and quality of life. Key findings are presented below.

Water Resources

The Great Lakes have historically enjoyed a relatively small range in lake levels – 6.5 feet from the recorded monthly maximum to the recorded monthly minimum. Superimposed on these levels are seasonal cycles of 10–12 inches. Recent declines from record high levels in the 1980s have caused concern among commercial shippers, hydroelectric companies, and recreational boaters. The dredging activities that may be used to offset some of the effects from low lake levels and channel depths are not without their own potentially negative consequences – namely the cost involved and the resuspension of pollutants that have remained dormant at the bottoms of channels for decades.

Previous assessments of how climate change would impact lake levels using output from steady-state GCMs have suggested that lake levels may decline by 1.5 – 8 feet by the end of the 21st century. In the current assessment, output from the CGCM1 model suggests that the evolution of a long-term trend toward lower Great Lakes levels may reach magnitudes of approximately a 1.5 to 3 feet drop on the various lakes within a time frame of about 3 decades. Output from the HadCM2 model suggests no change to a slight increase in lake levels. Ice cover will also likely decrease – both in terms of days with ice cover and thickness of ice.

Water regulation strategies should be developed that are robust enough for either high or low water levels. Water regulation models need to be developed to deal with some of the lake level changes that are anticipated from climate change.

Water Ecology

Aquatic life in the Great Lakes depends critically on how surface nutrients and oxygen are mixed throughout the depth of the lakes. The mixing in turn depends on the seasonal cycles of lake and air temperatures, sunshine, and winds.

The CGCM1 and HadCM2 models both suggest not only that the Great Lakes will be warmer, but that they will also remain

more stable for a longer portion of the year by the end of the 21st century. As a result, not as much oxygen will mix down from the surface to greater depths. This would effectively reduce the biomass productivity by around 20%.

The flow from the streams and rivers that feed into the lakes will also likely change. Inland rivers in the Great Lakes region that are primarily snowmelt driven (e.g., peak flows in early spring) may have earlier peaks as a result of less snow and more rain. Changes in summer flows for all rivers will likely depend on how the future increased precipitation that is suggested by the GCM simulations is balanced by evapotranspiration within watersheds.

The projected decline in primary production may require implementing stocking strategies to rebuild stocks of native species that have survived in the lakes through centuries of postglacial change and appropriate public education programs to explain such changes. Dredging attempts to maintain shipping channels should strive to minimize impacts on critical habitat required for spawning of native species and the nurturing of young.

Critical information needs include a better knowledge of how future precipitation and wind patterns will change over the Great Lakes drainage basin, how land-use practices will change, and how the links in the food web operate between the primary producers and the top, economically important fish.

Land Ecology

Three gradients characterize the natural ecosystems of the region: a southwest to northeast gradient from prairie to forest in Minnesota, a south to north gradient from Eastern deciduous to Northern mixed hardwood forests in Michigan and Wisconsin, and the Southern edge of the boreal forest extends into the region. The diversity of forest ecosystems throughout the region has contributed greatly to its prosperity and quality of life as well as its cleaner air and water, and the reduction of soil erosion.

Economically significant trees like quaking aspen, yellow birch, jack pine, red pine, and white pine may no longer be able to grow in the Great Lakes region because summers may become too warm. Other trees like black walnut and black cherry may eventually migrate northward into the region – given enough time. Productivity may ultimately increase, but only after a decline during the transition (a “dieback phenomenon”), as communities adjust to a changing environment. Because managed land use accounts for as much as three-quarters of the land area of natural ecosystems (i.e., grasslands), more information is needed on both the impacts that current land management has on the ability of vegetation communities to respond and how the dynamics of land use and management will interact with climate change.

Changes in the Great Lakes distributions of upland game birds may also occur. There may be more opportunities to hunt the Ring-necked Pheasant and Northern Bobwhite, but fewer to hunt the Sharp-tailed Grouse or Gray Partridge. There may also be fewer duck-hunting opportunities in the Great Lakes region. These changes are supported by recent observations. Some models project additional losses of neotropical migratory bird species in Michigan (32%), Minnesota (20%) and Wisconsin (32%). Particularly hard hit would be the wood warblers with large numbers of species projected to be extirpated from Michigan (61% lost), Minnesota (52% lost) and Wisconsin (67% lost). Losses are also projected for the other states within the Great Lakes region. These avifaunal changes will likely have negative impacts on the ecotourism and on ecosystem health in the region.

Reasonable response strategies within the forestry and land management communities include monitoring the health of the forests within their changing environment; implementing policies, such as land use planning and/or “sprawl” taxes to minimize land use conflicts; facilitating the migrations of plant species with the shifting of ecological zones; and planting tree species that are better suited to a changed climate.

An important research need is to couple models of ecosystem productivity with models of land use change to study change under altered climate.

Agriculture

Agriculture ranks among the most important economic activities of the Great Lakes region, accounting for more than \$15 billion in annual cash receipts. Livestock, including dairy, is the number one agricultural commodity group, comprising over half of the total. Dairy production alone produces almost \$5 billion in receipts. Crop diversity is an important characteristic of agriculture in the region due at least partially to the moderating influence of the Great Lakes on regional climate. Over 120 commodities are grown or raised commercially in the region.

The warmer and wetter climate across the region portrayed by both GCMs and the positive effects of CO₂ enrichment suggest that future crop yields may be greater than historical yields. Some crop yields may be greater than historical yields through 2050, but may then decrease with time from 2051-2100, especially at western and southern locations. Interannual variability of all projected future crop yields may tend to decrease with time, especially after 2050. Greater agronomic potential may be possible for northern sections of the region, even with less suitable soils. Simple adaptations to a changing climate such as a switch to a longer-season variety or earlier planting date were found to result in significant increases in potential crop yield.

Further analysis of the model simulations suggest that for the assessment decade of 2025-2034 lake-modified regions surrounding Lake Michigan will experience a moderate increase in growing season length and seasonal heat accumulation and a decrease in the frequency of subfreezing temperatures. In addition, important growth stages for perennials (such as commercial fruit trees) will occur earlier in the calendar year than at present. Very large changes in temperature threshold parameters are projected for the assessment decade of 2090-2099, especially for the eastern shore of Lake Michigan. It is unclear for

both assessment decades whether perennials (specifically, commercial fruit trees) will be more or less susceptible to damage from cold temperatures after critical growth stages have been reached. The simulations from the HadCM2 model suggest less susceptibility, whereas the simulations from the CGCM1 model suggest greater susceptibility.

Improvements in technology, the CO₂ fertilization effect, and the use of adaptive farm management strategies will mitigate any negative effects of climate change for the majority of farm operations in the Great Lakes region. Adaptive farm management strategies include: changes in crop selection or variety; using crop varieties that are currently used in more southern regions; changes in the timing of planting and harvesting, and the development of new varieties of crops that are more adaptable to interannual variations of weather.

Better regional- or local-scale climate models and more sophisticated agricultural models that include pesticide, fertilization, and CO₂ enrichment effects, as well as resulting economic impacts are needed for future assessments.

Quality of Life

A major quality of life issue is human health. People who lack protection to high temperature extremes eventually suffer from heat stress, dehydration, respiratory distress, and occasionally heat stroke or cardiac malfunction. Heat waves in the Great Lakes region are still relatively rare. Output from the HadCM2 and CGCM1 models suggests significant increases in the number of days above 90°F. Additionally, interannual variability may decrease – so cool summers may not occur as frequently as they do now. Other impacts from short-term, extreme weather events such as floods, tornadoes, and blizzards, may also increase in the Great Lakes region, because these events are forecasted to occur with increasing frequency – particularly heavy precipitation events.

Air pollution associated respiratory disease has not been well studied in the Great Lakes region. Results suggest that air pollutants are but some of many factors involved in the etiology of respiratory diseases. A simple analysis of the GCM output from the CGCM1 and HadCM2 models suggests that the number of days with synoptic patterns that are conducive to high ozone will increase by the end of this century across much of the Great Lakes region.

Improved weather forecasting, information distribution, special assistance, and economic well-being will help high risk populations to better cope with high temperature extremes. Improving the construction of future dwellings and preventing construction too close to lakeshores will help people in the region to better cope with heavy precipitation events. The impacts of air pollutants on health can be decreased if susceptible people such as the elderly or those with preexisting respiratory disease are warned to stay indoors during severe conditions outside. In some cases, a response may be to move from more polluted urban areas, or even to leave the Great Lakes region entirely for cleaner and drier climates.

The uncertainties in both the forecasts of possible climate change and the effects on public health demonstrate that major research and monitoring efforts are needed. More research is needed to better identify and understand the relationships between environmental factors and diseases.

Future Work

This first Assessment of Climate Change in the Great Lakes region suggests possible impacts from climate change. More importantly, it demonstrates the complexities that are associated with such a multi-disciplinary study. The uncertainties associated with projections in climate change are almost of secondary importance compared to some of the uncertainties associated with some of the sector-sector interactions, which for the most part have been ignored. Future endeavors will begin to address some of these important interactions.

Setting the Stage

1. INTRODUCTION

prepared by

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The Nation and the National Assessment Process

Climate affects many aspects of life in the US. Year-to-year variations are reflected in such things as the number and intensity of storms, the amount of water flowing in our rivers, the extent and duration of snow cover, and the intensity of waves that strike our coastal regions. Science now suggests that human activities are causing the climate to change. Although the details are still hazy about how large the changes will be in each region of the country, changes are starting to become evident. Temperatures have increased in many areas (Figure 1.1), snow cover is not lasting as long in the spring, and total precipitation is increasing, with more rainfall occurring in intense downpours. These changes appear to be affecting plants and wildlife. There is evidence of a longer growing season in northern areas and changing ranges for butterflies and other species. The international assessments of the Intergovernmental Panel on Climate Change (<http://www.ipcc.ch>) project that these changes will increase over the next 100 years.

The Global Change Research Act of 1990 [Public Law 101-606] gave voice to early scientific findings that human activities were starting to change the global climate:

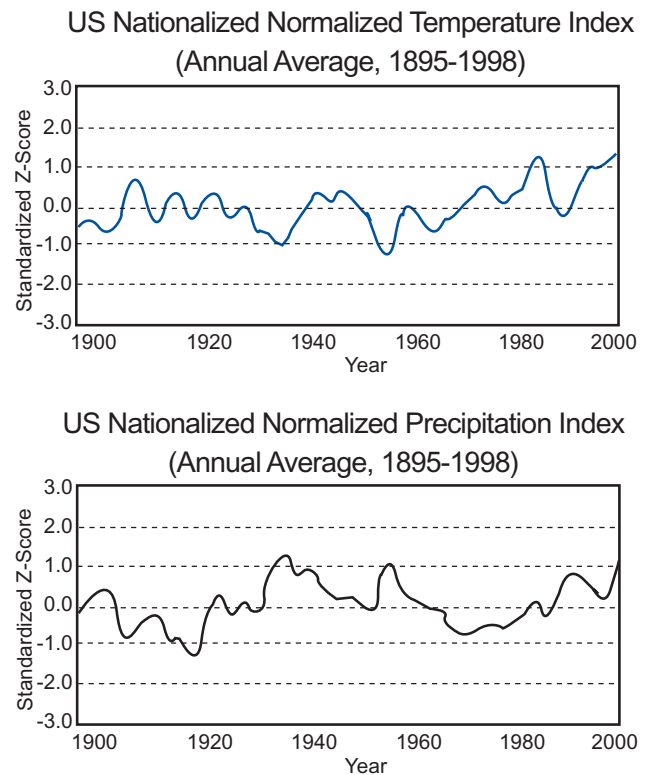


Figure 1.1: Temperature (upper) and precipitation (lower) trends for the US for the period 1900-2000. Source: National Climate Data Center, Tom Karl [1-1].

“(1) Industrial, agricultural, and other human activities, coupled with an expanding world population, are contributing to processes of global change that may significantly alter the Earth habitat within a few generations;

(2) Such human-induced changes, in conjunction with natural fluctuations, may lead to significant global warming and thus alter world climate patterns and increase global sea levels. Over the next century, these consequences could adversely affect world agricultural and marine production, coastal habitability, biological diversity, human health, and global economic and social well-being.”

To address these issues, Congress established the US Global Change Research Program (USGCRP) and instructed the Federal research agencies to cooperate in developing and coordinating “a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural process of global change.” Further, the Congress mandated that the USGCRP:

“shall prepare and submit to the President and the Congress an assessment which

- integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings;
- analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity;
- analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years.”

The USGCRP’s National Assessment of the Potential Consequences of Climate Variability and Change, which is focused on the question of why we should care about and how we might effectively prepare for climate variability and change, is being conducted under the provisions of this Act (Figure 1.2).

The overall goal of the National Assessment is to analyze and evaluate what is known about the potential consequences of climate variability and change for the Nation in the context of other pressures on the public, the environment, and the Nation’s resources. The National Assessment process has been broadly inclusive, drawing on inputs from academia, government, public and private sectors, and interested citizens. Starting with broad public concerns about the environment, the Assessment is exploring the degree to which existing and future variations

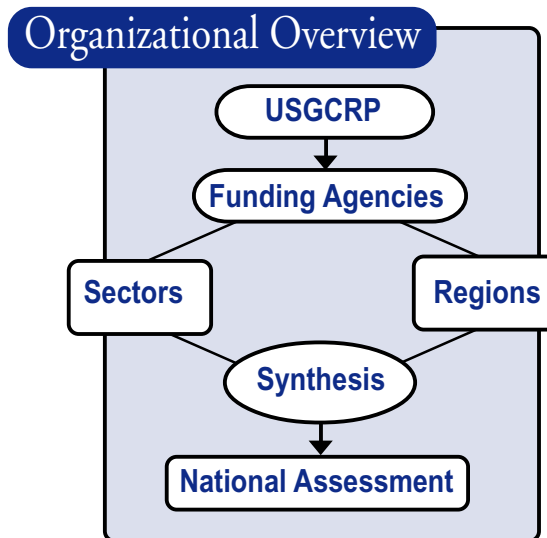


Figure 1.2: Organizational overview for the National Assessment.

and changes in climate might affect issues about which people care. A short list of questions has guided the process as the Assessment has focused on regional concerns around the US and national concerns for particular sectors:

- What are the current environmental stresses and issues that form the backdrop for potential additional impacts of climate change?
- How might climate variability and change exacerbate or ameliorate existing problems? What new problems and issues might arise?
- What are the priority research and information needs that can better prepare the public and policy makers for reaching informed decisions related to climate variability and change? What research is most important to complete over the short term and over the long term?
- What coping options exist that can build resilience to current environmental stresses, and also possibly lessen the impacts of climate change?

Three National Assessment Components

Regional Analyses

The National Assessment includes regional, sectoral, and synthesis activities.

Workshops and assessments are being conducted to characterize the potential consequences of climate variability and change in regions spanning the US. A total of 19 workshops (Figure 1.3) were held around the country, with the Native Peoples/ Native Homelands workshop being national in scope rather than regional. To date, 16 of these groups are preparing assessment reports. The reports from these activities address the interests of those in the particular regions by focusing on the regional patterns and texture of changes where people live. Most workshop

reports are already available and assessment reports will start to become available in early 2000.

Sectoral Analyses

Workshops and assessments are being conducted to characterize the potential consequences of climate variability and change for major sectors that cut across environmental, economic, and societal interests. The sectoral studies analyze how the consequences in each region affect the Nation, making these reports national in scope and of interest to everyone. The sectors being addressed in this first phase of the ongoing National Assessment include Agriculture, Forests, Human Health, Water, and Coastal Areas and Marine Resources. Sectoral assessment reports will be made available in 2000.

National Overview

The National Assessment Synthesis Team has responsibility for summarizing and integrating the findings of the regional and sectoral studies and then drawing conclusions about the importance of climate change and variability for the United States. Their report will be available during 2000.

Each of the regional, sectoral, and synthesis activities is being led by a team comprised of experts from both the public and private sectors, from universities and government, and from the spectrum of stakeholder communities. Their reports have all gone through an extensive review process involving other experts and other interested stakeholders and are available on request (see <http://www.nacc.usgcrp.gov>). The assessment process is supported in a shared manner by the set of USGCRP agencies, including the Departments of Agriculture, Commerce (National Oceanic and Atmospheric Administration), Energy, Health and Human Services, and Interior, plus the Environmental Protection Agency, National Aeronautics and Space Administration, and the National Science Foundation. Through this involvement, the USGCRP is hopeful that broad understanding of the issue and its importance for the Nation will be gained and that the full range of perspectives about how best to respond will be aired.

Sectors and Regions

Sectors

- Agriculture
- Forests
- Human Health
- Water
- Coastal Areas/Marine Resources

Regions

- Alaska
- Appalachians
- California
- Eastern Midwest
- Great Lakes
- Great Plains - Central
- Great Plains - Northern
- Southern Great Plains/Rio Grande
- Gulf Coast
- Pacific Islands
- Metropolitan East Coast
- Middle Atlantic
- Native Peoples/Native Homelands
- New England
- Pacific Northwest
- Rocky Mountain/Great Basin
- South Atlantic Coast & Caribbean
- Southeast
- Southwest

Figure 1.3: Sectors and regions in the National Assessment.

The Region and the Regional Process

The Great Lakes region has been a leader in certain areas of agriculture and industry for the better part of this century. The nickname “The Industrial Heartland” is well earned. Additionally, the Great Lakes themselves are an important resource for transportation as well as recreation [1-2]. Changes in lake levels in past years have affected the way people live, work, and recreate in the region. Periods of high water, like that which occurred in the 1980s, can be beneficial for shipping, but can be detrimental for lakefront property owners – especially during stormy periods. Periods of low water, like that which occurred in the 1990s, can be detrimental to shippers, requiring them to carry lighter loads, but attractive to people looking to build vacation homes near the lakes. Understanding what lake levels will do in the future is information that many people would like to have. While many meteorological factors are involved in understanding what lake levels will do in the future, an overarching concern is how climate change will affect lake levels. Thus, there is strong motivation to understand how climate change will affect the Great Lakes region.

Despite the concerns that many people who live in the region (i.e., the region’s stakeholders) have regarding not just the potential impacts that climate change will have on lake levels but also regarding other aspects or sectors within the region, little attention has been paid. For example, telling stakeholders that temperatures will increase by so many degrees and that precipitation will increase by so many inches per year is inadequate for their purposes. These stakeholders have individual needs that are driven by their professional and personal interests – needs that can not be answered by degrees of mercury or inches of water. These stakeholders want to know whether they can ship goods the way they used to, or whether they can build their dreamhouse on the shores of Lake Michigan, or whether they can continue to enjoy their birdwatching or leafpeeping activities. Answering these types of questions requires a different type of approach that extends beyond the numbers that climate models

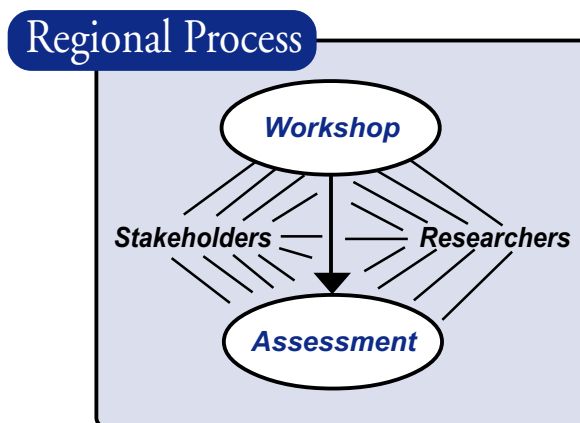


Figure 1.4: The Great Lakes Regional Assessment process.

can provide. Answering these questions takes a coordinated effort between the stakeholder and research communities.

In the Fall of 1997, planning began for a workshop that would initiate a relationship between the stakeholders and researchers in the Great Lakes region (Figure 1.4). The workshop was to be one of the 19 regional workshops that were being sponsored by the USGCRP. The workshop would address several questions, including how climate change would impact certain sectors. Thus, a key piece of information was knowing which sectors were important. While this could have ideally been addressed at the workshop, it was decided to choose broadly defined sectors beforehand and then let the workshop attendees decide what aspects specifically within each of the sectors were highly important. To this end, a steering committee was chosen to identify the sectors that would be discussed at the workshop. The steering committee consisted of people from academia, government, environmental interest groups, and industry.

Over one hundred people from academia, government, environmental interest groups, and private industry attended the workshop, which was held at the University of Michigan during May 4-7, 1998. A series of invited talks ensured that participants had some common knowledge as they divided into breakout groups to discuss the above mentioned four assessment questions and how they related to important regional sectors: water resources (WRES), agriculture (AGRI), water ecology (WECO),

land ecology (LECO), economy (ECON), infrastructure (INFR), and human health (HLTH). The discussions from the breakout groups were summarized and used to determine some of the more important concerns regarding climate change (impacts) in the Great Lakes region. Although the discussions regarding stresses and the impact of climate change on those stresses were obviously sector-dependent, two common themes arose from all sector-breakout groups. One was that better models – not just better regional climate models – but better coupled models of climate and streamflow, for example, or climate and agricultural yields, as another example, need to be developed for the region. Another common theme was that stakeholders and the general public need to be better informed (educated) regarding the potential impacts of climate change [1-3].

The choices for which sectors, and what aspects within those sectors to assess, and what goals to accomplish was decided by members of the workshop steering committee with input from the workshop results (Figures 1.4 and 1.5). Identifying members for the Great Lakes Regional Assessment Team with suffi-

cient interest, expertise, and availability to address the most important aspects proved challenging and in some instances the choices for what to investigate were adjusted.

Part of the Great Lakes Regional Assessment strategy also involved engaging researchers from other institutions in the Great Lakes region. For example, while the University of Michigan hosted the Upper Great Lakes Workshop, and is the Central Headquarters for the Great Lakes Regional Assessment effort, other institutions have certainly collaborated. Because the bottom line of this assessment is to get the message about climate change impacts across to the stakeholders throughout portions of an eight-state region, it was deemed advantageous to involve researchers from The University of Minnesota (Minneapolis-St. Paul, Minnesota), The University of Wisconsin-Milwaukee (Milwaukee, Wisconsin), The Illinois State Water Survey (Champaign-Urbana, Illinois), Michigan State University (East Lansing, Michigan), the Army Corps of Engineers (Buffalo, New York), The Great Lakes Environmental Research Laboratory (Ann Arbor, Michigan), The Center for Environmental Policy, Economics and Science (CEPES), (Ann Arbor, Michigan), and of course from the University of Michigan (Ann Arbor, Michigan).

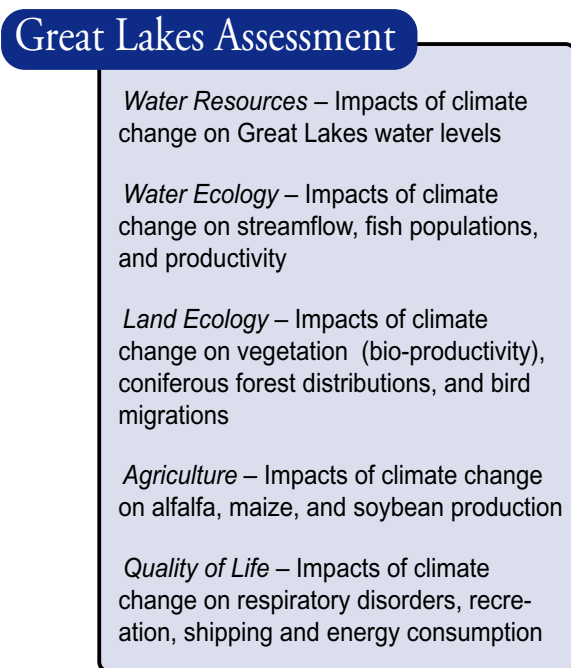


Figure 1.5: Sectors that were examined in the Great Lakes Regional Assessment.

All the researchers involved in the National Assessment, not just those from the Great Lakes region, were asked to follow some “loose” guidelines regarding their assessment. One guideline was to use some of the latest output from General Circulation Models (GCMs). Prior to the mid 1990s, most climate change simulations by GCMs did not include effects from aerosols, which people believe to be the reason why the global temperature has not risen more rapidly, given the amount of additional CO₂ that is in the atmosphere. The presence of aerosols effectively increases the albedo, and reflects some of the sun’s energy back to space. At the time, output from GCMs that included aerosols was available from the Canadian Coupled-Climate Model (CGCM1), and from the Hadley Centre Climate Model (HadCM2). These models have slightly different parameterization schemes for many of the sub-grid scale processes

[1-4, 1-5]. A summary of their temperature and precipitation output for the Great Lakes region is provided in the next chapter. Researchers were encouraged to examine output from both models – although time constraints prevented many from doing so. In the Great Lakes region, it was decided to focus more on analysis of output from the Hadley Model, owing to the fact that the Great Lakes were not included in the Canadian Model simulations. Some researchers in the Great Lakes region did examine output from the Canadian model as well, because of additional concerns. The climate scenario output from the models were available in several forms. Daily output from the Canadian model (3.75° latitude by 3.75° longitude) and from the Hadley model (2.5° latitude by 3.75° longitude) was available for sea-level pressure, winds, temperatures, and geopotential heights at selected pressure levels, as well as surface maximum and minimum temperatures and precipitation. Climate scenario output was also available from the VEMAP (Vegetation/Ecosystem Modeling and Analysis Project) process as monthly means and daily values [1-6] at 0.5° x 0.5° resolution. The attraction to some researchers for using VEMAP output stemmed from its higher spatial resolution and more realistic (ranges of) daily temperature and precipitation values. The VEMAP monthly means were simply interpolated directly from the GCM monthly

means. The daily values, however, were created in a more complicated way. Rather than use the daily output directly from the GCMs, the GCM monthly means were processed through a *weather generator* program [1-6], that created more realistic daily variations than the GCM could. Daily VEMAP output at each point was created using parameter values that were climatologically appropriate for that particular region. As a result, there was no attempt to assure that the fields were spatially correlated. The VEMAP fields consisted of surface maximum and minimum temperatures, precipitation, and some surface moisture and radiation fields. No sea-level pressure, wind, or geopotential height information was available in VEMAP form.

Researchers were also asked to consider future socioeconomic scenarios. This consideration was less straightforward than that of climate change. However, the strategy in the end was to make an attempt to account for changes in population, landuse, and overall wealth when considering the impacts of climate change on a particular sector. The socioeconomic data was provided on a series of three CD-ROMs from NPA Data Sources, Inc. [1-7].

Owing to severe time constraints, most researchers used an overlay approach (Figure 1.6) for assessing impacts. An overlay approach means that researchers evaluated the impacts from climate change as indicated from (quantitative) output from the GCMs by interpolating or extrapolating results from previous assessments. The overlay approach provided a simple, efficient, and accurate means to evaluate climate impacts from the newly available model output in most instances. However, one fundamental constraint of this approach is that the accuracy of the new results is inherently limited by the accuracy of the old results. Unfortunately, there was little time for a more fundamental approach, e.g., refining existing or developing new impacts assessment models – like stakeholders had suggested at the workshop. The specific approaches used by the different researchers are described in more detail in chapters 4-8.

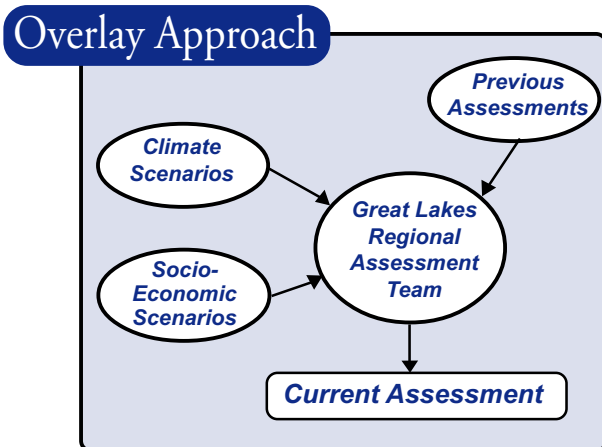


Figure 1.6: The overlay approach used by many investigators during the Great Lakes Regional Assessment.

The Great Lakes Region: Past, Present, and Future

2. HISTORICAL OVERVIEW AND CURRENT SITUATION

prepared by

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The Great Lakes region, for the purpose of this report, consists of the Great Lakes drainage basin, Wisconsin and Minnesota. The drainage basin includes portions of Ontario and Quebec, as well as portions of Minnesota, Wisconsin, Illinois, Indiana, Ohio, Pennsylvania, and New York, and all of Michigan. The Great Lakes themselves are the geographical centerpiece of the region. The Lakes and other physical characteristics of the region were formed nearly 3 billion years ago, during the Precambrian Era. Early sedimentary and volcanic rock were repeatedly heated, folded, and eroded into the gentle rolling hills that still exist today in the northwestern portions of the region as part of the remnants of the Canadian Shield. The Paleozoic Era brought repeated flooding by marine seas, which were responsible for the formation of a layer of sedimentary rock consisting of limestone, shales, sandstone, halite, and gypsum — remnants of marine life. The Pleistocene Epoch brought with it repeated advancements and retreats of glaciers — sometimes over a mile high — to the region. The glaciers scoured the terrain, leveled hills, and turned river valleys into what now constitute the Great Lakes drainage basin. Each glacial retreat left behind a mixture of sand, silt, clay, and boulders — the glacier drift. The melting water from the glaciers filled the deeply scoured regions as lakes that were even larger than the present

day versions. The warm periods also allowed vegetation and wildlife to return to the region before the next glacial advance began scouring the region once more.

The Great Lakes - St. Lawrence Basin watershed spans an area of about 400,000 mi² (1,000,000 km²). Twenty five percent of that amount, 100,000 mi² (250,000 km²), is covered by the Great Lakes themselves. These Lakes contain over six quadrillion gallons of water — nearly 20% of the world's fresh water supply. Only the polar ice caps contain more fresh water. The water in the Great Lakes-St. Lawrence Basin serves as a resource for sustaining human life, ecology, agriculture, trade, energy generation, and recreation, to name a few.

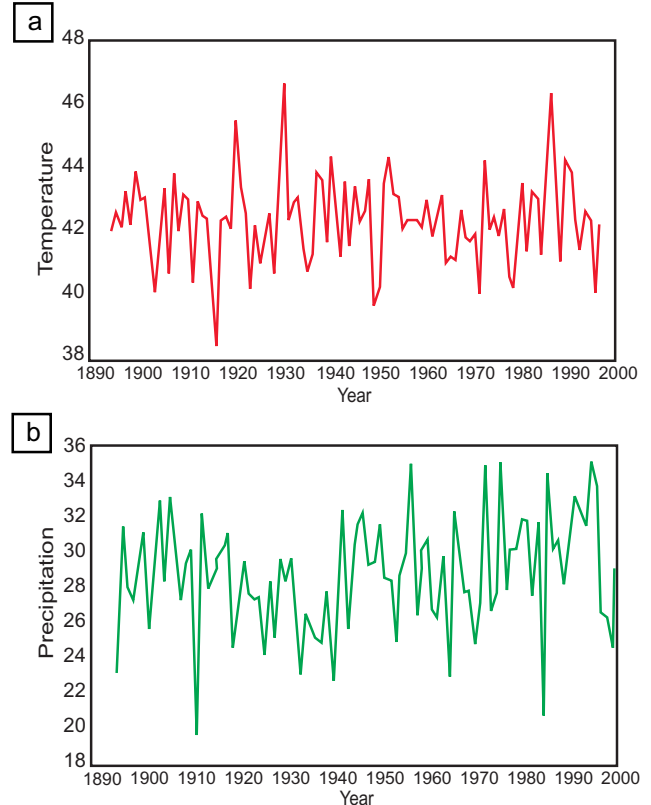


Figure 2.1: Historical trends of mean a) temperature and b) precipitation for Upper Great Lakes region: Michigan, Minnesota and Wisconsin. [2-1].

Climate

The region's location within the interior of the North American continent contributes to the current (non-glacial) climate characteristics consisting of warm summers, cold winters, and significant amounts of precipitation year-round (Figures 2.1 and 2.2). Additionally, the Great Lakes are large enough and close enough to each other to exert significant impacts on local and regional weather. Areas in the north and west (International Falls, Minnesota) have lower temperatures, a larger seasonal temperature range, and less annual and less seasonally distributed precipitation than areas in the south and east (Detroit, Michigan). Areas close to the lakes (Traverse City, Michigan and Buffalo, New York) have a smaller annual temperature range

than areas farther away (Lansing, Michigan). The primary moisture source is the Gulf of Mexico, although the Pacific and Atlantic Oceans are not insignificant sources.

In winter, nighttime low temperatures typically range from sub-zero in the northwest to the teens (°F) in the southeast. Strong low pressure systems typically approach the region from the southwest, bringing Gulf of Mexico moisture to the region in the form of heavy rain, snow, or a frozen mix. Weaker systems with less moisture from the Pacific or Canada (Alberta Clippers) approach from the west or northwest [2-1]. As these systems move through the region, northwesterly flow on the back sides of the lows can bring bitterly cold (arctic) air masses into the Great Lakes region. Temperatures can plunge to -40°F or

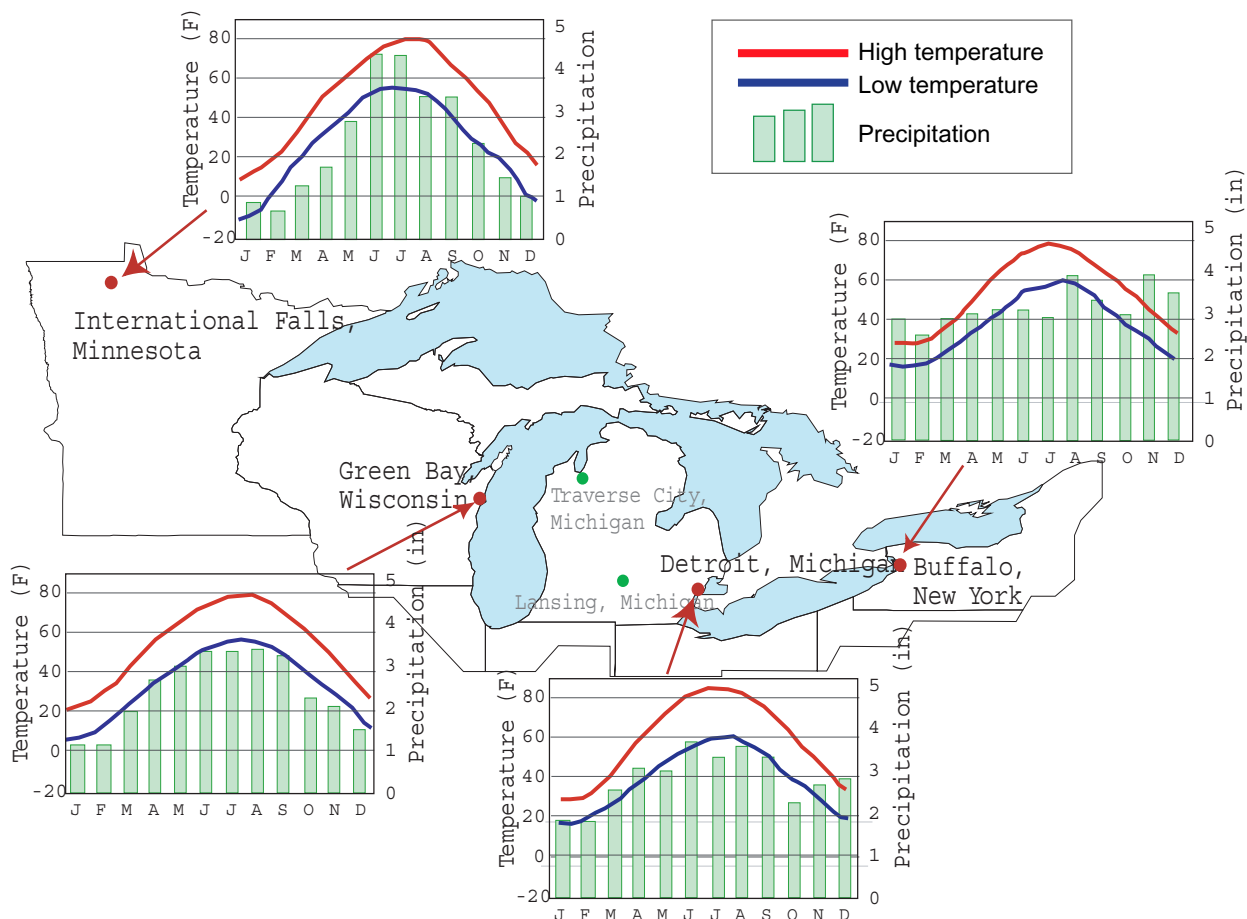


Figure 2.2: Monthly high and low temperatures (red curves, °F), and precipitation (bars, inches) for International Falls, Minnesota, Green Bay, Wisconsin, Buffalo, New York, and Detroit, Michigan [2-2].

lower, especially in the northern parts of the region. As this cold air travels across the much warmer lakes, it is warmed, moistened, and destabilized. Intense lake-effect snowstorms typically develop on the leeward sides of the lakes. Snow storm totals can often exceed 10 inches. Lake-effect snows are most prominent along the southern and eastern shores of Lake Superior, the eastern shores of Lakes Michigan and Huron, and the southeastern shores of Lakes Erie and Ontario where such snow can account for more than half of the annual snowfall totals [2-3]. For example, 80 of the 160 inches that usually fall in Traverse City, Michigan typically come from lake-effect. The amount of lake-effect snow that any location gets in any year depends on how much cold air and what the prevailing wind direction is among other factors. During El Niño years, lows move north and/or west of the region, typically bringing less precipitation, fewer cold air outbreaks, and less (lake-effect) snow.

A northward retreat of the jet stream during the summer allows relatively tranquil conditions to exist most of the time. Daytime high temperatures range from near 80°F (26°C) in the northwest to the mid 80s °F (30°C) in the southeast. Cooler conditions exist near the lakeshores. Southerly flow on the back side of the Bermuda High can bring high heat and humidity from the Gulf of Mexico and the Atlantic Ocean into the region. Although low pressure centers rarely cross through the region in summer, cold fronts do move through the region every 1-2 weeks, bringing at times severe weather, intense precipitation, and relief from intense heat. Tornadoes range in frequency from 1-2 per year in the northwest to 2-4 per year in the southeast to 12-16 per year just south of Chicago (Figure 2.3). As a result of the more tranquil large-scale flow, the lakes play a significant role near the lakeshores. Lake-air temperature differences affect thunderstorm and possibly tornado development in complicated ways. For example, near Lake Michigan, lake-land temperature differences lead to thunderstorm increases in the north but thunderstorm decreases in the south. On the whole, the lakes themselves are estimated to account for a net decrease (e.g., ~6% for Lake Michigan) of summertime precipitation over the Lakes. In Fall, the lakes contribute to hail storms that can cause considerable crop damage [2-4].

Population & Economy

The first inhabitants of the region moved in as last glacier retreated nearly 10,000 years ago. A few thousand years later, the natives had established hunting and fishing communities and were using copper from the region. They grew corn, squash, beans, and tobacco and moved once or twice each generation when the resources in an area became exhausted. By the sixteenth century, an estimated 60,000-120,000 Native (Americans) occupied the region before the region began being settled by Europeans [2-1].

The area was first settled primarily by the French, but soon thereafter by the British, and Americans. The Native American people were slowly squeezed out (of existence, in many cases). A series of military struggles between the French and the British and Americans culminated with the war of 1812. Both the Americans and the British claimed victory. The Native Americans, who were involved to save their homeland, did not share in the victory.

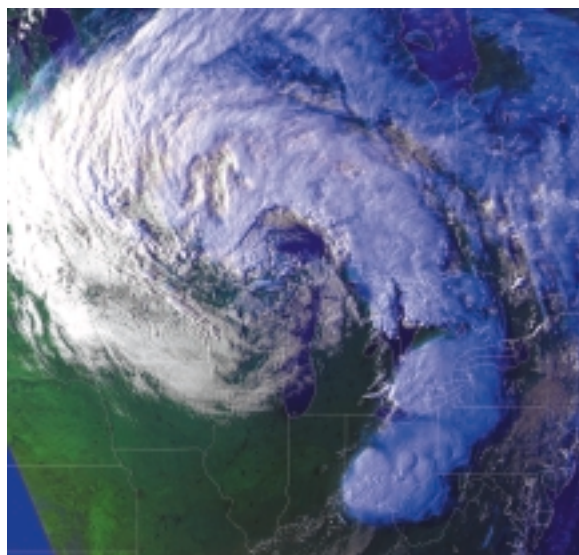


Figure 2.3: Visible satellite image of a tornado outbreak taken at 2335 UTC 02 July 1997. Source: National Oceanic and Atmospheric Administration (NOAA), The National Environmental Satellite, Data and Information Service (NESDIS), Operational Significant Event Imagery (OSEI).

Development of the region from that time to the present has evolved dramatically. The population alone since 1900 has increased from approximately 10 million to over 40 million (Figure 2.4). In the last half of the 19th century, lumbering, farming, mining, and early manufacturing dominated the economies of Michigan, Wisconsin and Minnesota – the Upper Great Lakes region.

Lumbering began as early as the 1830s and grew throughout the region. In the period after the Civil War it became a dominant industry, with Michigan woodlands alone producing about a quarter of the nation's total supply. The harvest of wood resources was rapid and unsustainable. By the 1870s the great forests of the region were drastically reduced.

The climate and fertile soil of Michigan, Wisconsin, and Minnesota were ideal for wheat production. Between the 1880s and the 1920s the prairies and valleys were converted to a checkerboard of fields and pastures. During this period Minneapolis became the country's largest producer of flour. Like lumber, the prairie soil was depleted and farmers had to turn from wheat to a mix of crops.

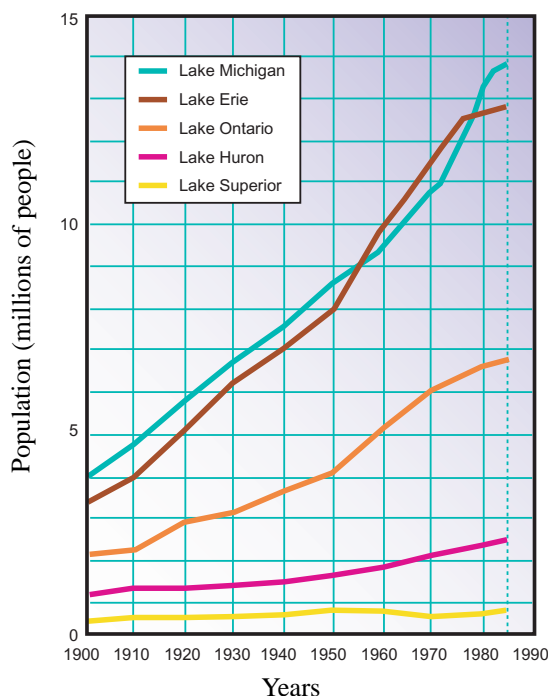


Figure 2.4: Population growth in the Great Lakes basin since 1900 [2-1].

Iron ore mining in Minnesota began in the 1890s as thousands of laborers worked on the Mesabi, Vermillion and Cuyuna iron ranges. They built towns and dug huge pits to remove the valuable ore. The Hull-Rust mine in Hibbing, Minnesota became the largest open-pit mine on Earth.

Henry Ford, R.E. Olds, William Durant, and Walter Chrysler used the assembly line to make automobile manufacturing the greatest wealth creator of the 20th century. Like lumbering and mining before it, automobile manufacturing needed labor and it drew people to the region, this time in unprecedented numbers.

Between 1900 and 1930 Flint grew by a factor of 12 to 156,000 people and Detroit grew from less than 300,000 to 1.6 million! Earlier immigrants were from Canada and Europe with very large numbers of Germans going to Wisconsin. The automobile industry brought immigrants from new areas such as Poland, Hungary, Italy and Greece as well as African-Americans from the south. The Great Lakes-St. Lawrence Basin is now home to more than 42 million Americans and Canadians. An estimated 97% of Quebec's population lives within the St. Lawrence River Basin watershed; two-thirds of its population lives within a 6 mile (10 km) wide strip on either side of the St. Lawrence River [2-5].

Although there has been dramatic change in the economic structure of the Upper Great Lakes region over the past 200 years, Minnesota still provides about 70% of the iron ore/taconite produced in the US; automobiles are still a very large component of Michigan's economy dominating the durable goods manufacturing sector; and farming is a \$2 billion/yr industry in Wisconsin.

The Great Lakes region as a whole is suitable for growing eight of the top ten food crops in the world. Hog production is important in Minnesota, dairy production is important in Wisconsin, and specialty crops are important in Michigan, which ranks first in the US in tart cherry production. The wine industry is

important in upstate New York. Other specialty crops are important elsewhere. These specialty crops grow well in these areas, in part because of microclimates that are unique to the region.

The St. Lawrence Seaway is currently the world's longest deep draft inland waterway. It consists of a series of 19 locks and 6 canals spread across 60 miles. The locks can raise ships that are 730 feet in length and 76 feet at the beam more than 591 feet above sea level. The Seaway serves 50 regional ports as well as a region that: 1) is home to more than 90 million people (nearly 25% of North America's population); 2) creates more than a third of the continent's gross national product; 3) produces two-thirds of Canada's industrial output; 4) grows almost half the soybean and corn in the US; and 5) accounts for some 40% of US manufacturing. It allows access to 15 major ports that ship products around the world. The Seaway allows shipping routes to Europe that are shorter than comparable routes from east coast cities. It is used for commercial shipping and pleasure craft traffic. Four principal dry bulk commodities (iron ore, limestone, coal, and grain) constitute 85% of the regional shipping industry. Fourteen regional companies use the Great Lakes - St. Lawrence Basin for shipping. The Seaway has carried more than two billion tons of cargo and has accounted for \$300 billion in trade since its opening in 1959. The Seaway is managed and operated by The St. Lawrence

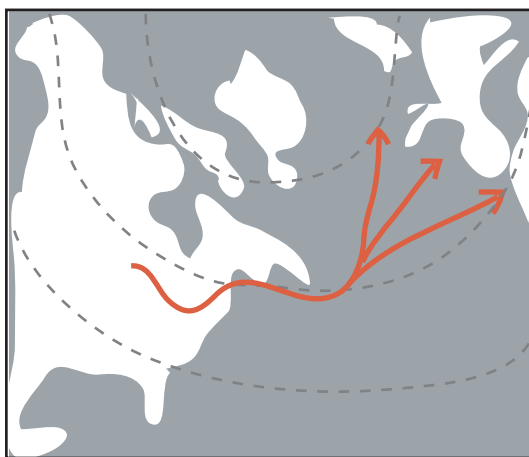


Figure 2.5: Common shipping routes from the Great Lakes to Europe [2-7].

Seaway Authority of Canada and the United States Saint Lawrence Seaway Development Corporation. It is currently open to navigation from early April to mid-December [2-6].

The New York Power Authority provides about a quarter of New York State's electricity by operating 12 generating facilities and more than 1,400 miles of transmission lines. Two hydroelectric facilities on the St. Lawrence River are the St. Lawrence-Franklin D. Roosevelt Power Project and the Niagara Power Project. The St. Lawrence-Franklin D. Roosevelt Power Project has a net dependable capability of 800,000 kilowatts. The Niagara Power Project has a net dependable capability of 2,400,000 kilowatts. Together these two facilities supply more than 10% of New York State's electricity. Or put another way, they supply enough electricity to light Washington, D.C. four times over [2-8]!

Ontario Power Generation is one of the largest utilities in North America in terms of installed generating capacity. Ontario Power Generation (formerly Ontario Hydro), a self-sustaining corporation without share capital, was created by provincial statute and operates today under the Power Corporation Act of Ontario. Its net dependable capability of 30,284,000 kilowatts is generated from: 69 hydroelectric stations, 5 nuclear stations, and 6 fossil-fueled stations [2-9].

Summer and winter recreation are economically important to the region. There are more registered boaters in the state of Michigan than in any other state. The eight state region as a whole accounts for nearly one-third of all registered boaters in the US. The large numbers demonstrate the importance of recreational boating to the regional economy. The boating industry is represented by boat manufacturers and retailers, marina operators, marine business suppliers, and the hundreds of thousands of boaters and anglers. Retail sales of marine equipment in 1988 accounted for more than \$3 billion in spending.

3. POTENTIAL FUTURES

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Climate

The regional climate through the end of the 21st century will likely be warmer and wetter. The questions of how much warmer and how much wetter may be answered by examining output from two General Circulation Models (GCMs): the Canadian Model (CGCM1) [1-4] and the United Kingdom Hadley Model - (HadCM2) [1-5]. These models differ from ones in the recent past not only in their sophistication with which they handle cloud development and ocean currents for example, but also because they are transient and they include the effects of aerosols. These aerosols mask the warming effects of increasing carbon dioxide, an effect which will only likely be temporary. The steady-state nature of previous models only allowed an evaluation of effects from an "instantaneous doubling of CO₂," rather than from a more realistic steady increase. The two models recreate the current conditions [3-1] well but suggest slightly different climate scenarios for the Great Lakes region.

Figures 3.1 and 3.2 show that in general, the CGCM1 scenario is warmer and drier than the HadCM2 scenario. The models differ only slightly for the period 2025-2034 in summer. The models suggest that minimum summer temperatures will increase by 1.8-3.6°F (1-2°C) across the region, while maximum temperatures will increase 0-1.8°F (0-1°C). More

warming will occur in the western part of the region than in the eastern part. The net change may be a decrease in the diurnal temperature range in the west and an increase in the east. The decreased diurnal temperature range may suggest slightly more cloudiness or humidity over the western part of the region. The models also suggest that summer precipitation will increase by 15-25%.

Larger differences between the two models exist in winter. Increases in the minimum temperature of 7.2 - 10.8°F (4-6°C) from southeast to northwest are projected by the CGCM1 scenario and 0.9-4.5°F (0.5-2.5°C) from east to west by the HadCM2 scenario. Increases in the maximum temperature of 3.6 -5.4°F (2-3°C) from north to south are projected by the CGCM1 scenario, and increases 0.9-4.5°F (0.5-2.5°C) from west to east by the Hadley scenario. Wintertime precipitation is slightly less in the HadCM2 than in the CGCM1 scenario, which generates precipitation that is similar to present day values.

Both models suggest more significant changes in mean temperature and precipitation for the period 2090-2099, than for the period 2025-2034. They also differ from each other more. For example in summer, the CGCM1 scenario shows average temperature increases of 7.2°F (4°C), while the HadCM2 scenario shows increases around 3.6°F (2°C). Precipitation varies considerably across the region and between the two models also. The CGCM1 scenario shows near-drought conditions across the northwestern portion of the region and increases of 20-40% everywhere else. The HadCM2 scenario shows general precipitation increases of 25% with near flood conditions (increase of 70%) over northern lower Michigan.

In winter, the CGCM1 scenario shows average temperature increases of 10.8-12.6°F (6-7°C). More warming occurs for the minimum temperatures and more warming occurs to the south

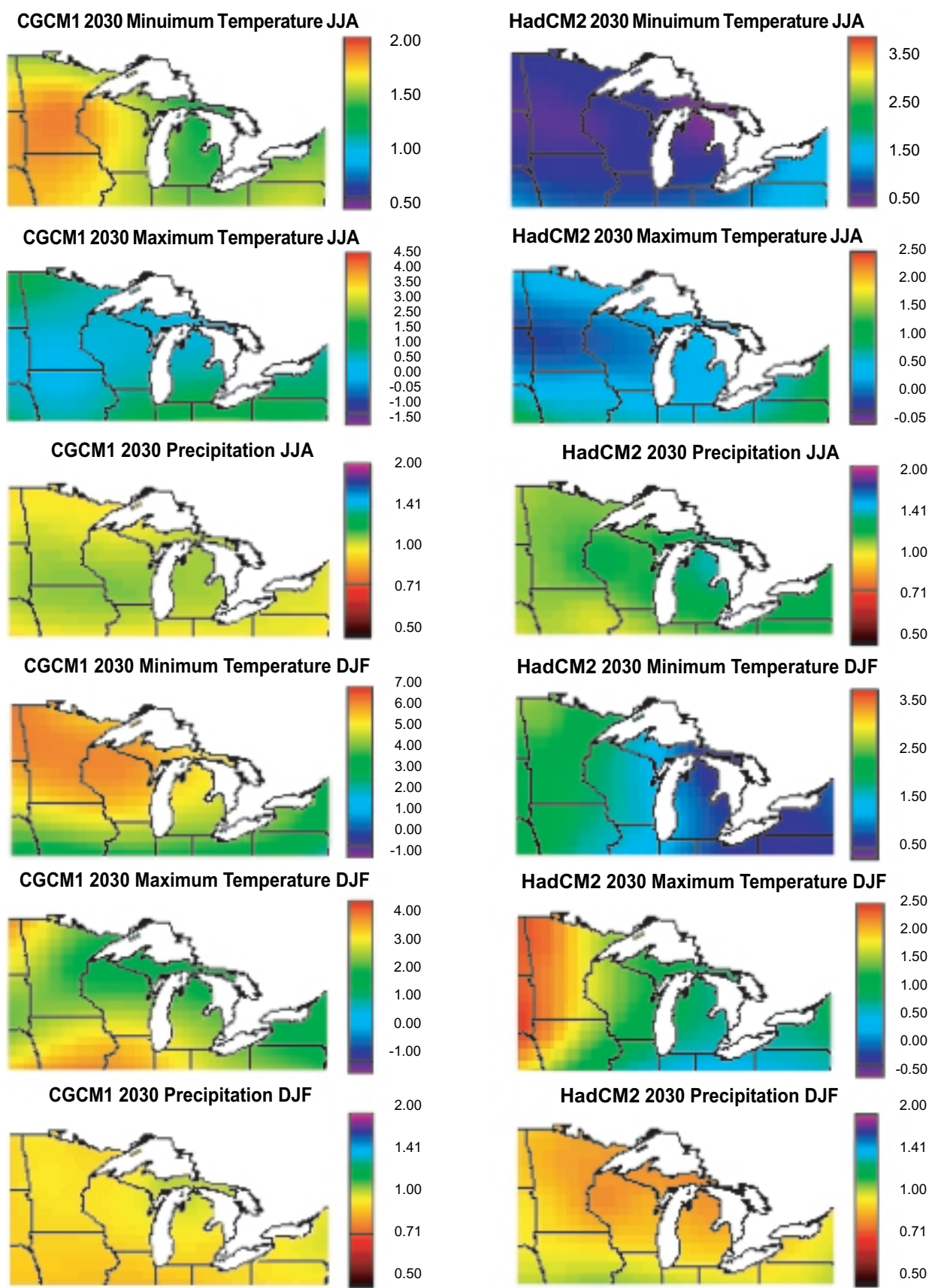


Figure 3.1: Future climate projections from the Hadley (HadCM2) and the Canadian (CGCM1) general circulation models for winter (DJF) and summer (JJA) for the period 2030. Plotted values are for VEMAP averages at 0.5° resolution. Output includes maximum (MAX) and minimum (MIN) surface temperature changes (°C) and precipitation changes (%) from baseline (1961-1990) model scenarios [3.2].

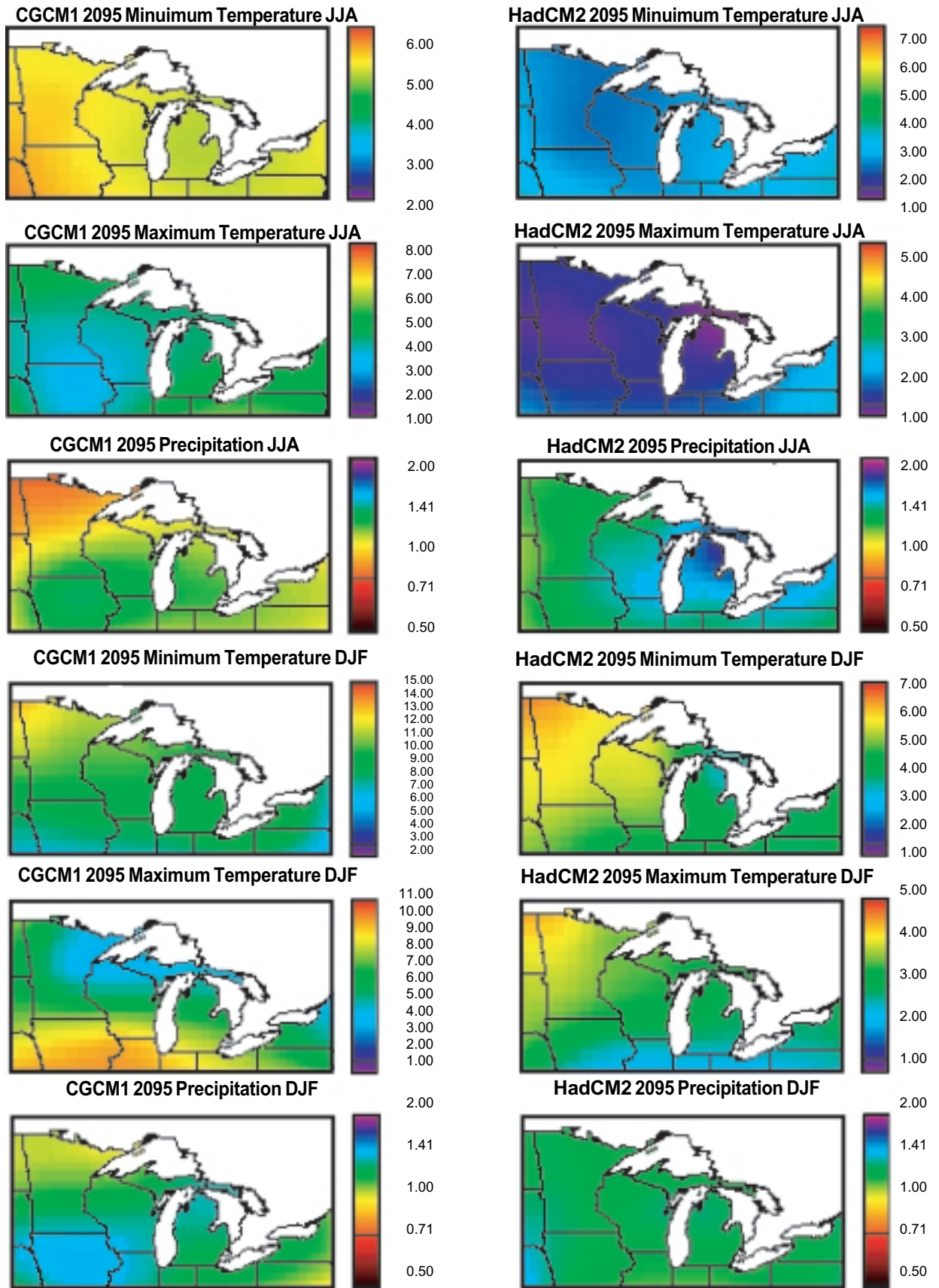


Figure 3.2: Future climate projections from the Hadley (HadCM2) and the Canadian (CGCM1) general circulation models for winter (DJF) and summer (JJA) for the period 2095. Plotted values are for VEMAP averages at 0.5° resolution. Output includes maximum (MAX) and minimum (MIN) surface temperature changes ($^\circ\text{C}$) and precipitation changes (%) from baseline (1961-1990) model scenarios [3.2].

than to the north — suggesting an enhanced horizontal temperature gradient and possibly an enhanced storm track. The HadCM2 scenario shows average temperature increases of 7.2°F (4°C) with a weakening of the horizontal temperature gradient. Both models show about a 20% increase in precipitation across much of the region. The CGCM1 scenario shows a 40% increase over Iowa — just to the southwest of the Great Lakes region.

Understanding the mean temperature and precipitation changes from the models is important, but understanding the corresponding day-to-day weather (and weather extremes) associated with those changes is tantamount to being able to understand and to deal with climate change. Unfortunately, such changes are difficult enough to assess in winter and even more difficult in summer. However, some assessments of local weather changes can be made based on the model projections of large scale conditions and simple statistics. For example, the probability that Chicago will experience 10 or more days in the summer with high temperatures exceeding 90°F (32°C) is projected to go from a 1-in-25 year event now to a 1-in-10 year event by the end of next century. The probability that Chicago will experience 6 or more days in the winter with low temperatures below 0°F (-18°C) is projected to go from a 1-in-10 year event now to a 1-in-50 year event by the end of the 21st century. By the end of the 21st century, the typical winter may be comparable to what we experience now during a moderate to strong El Niño. The coldest winters may be comparable to the normal winters we experience now. Snowfall totals may be half the current normal totals with lake-effect snow being significantly reduced (Focus: *Climate Change and Lake Effect Snow*), but lake-effect rain being increased. Both the CGCM1 and the HadCM2 scenarios suggest more zonal flow patterns. In winter this translates to more Pacific systems, more Gulf of Mexico systems, and fewer Alberta Clippers. Alberta Clippers are a primary source for reinforcing cold air over the Great Lakes in winter. Fewer outbreaks likely means less lake-effect snow.

Population & Economy

In some sense it is considerably more difficult to imagine what the future socioeconomic situation for the Great Lakes region

GENERAL CIRCULATION MODEL (GCM) QUICK COMPARISON

Model	HadCM2	CGCM1
Type	Transient	Transient
Aerosols	Included	Included
Precipitation	much wetter	wetter
Temperature	warmer	much warmer
Great Lakes	Included	Not included

will be than to consider how the climate itself will change. For example, the auto industry is one of the leading industries in the region, and while its existence is certainly not in jeopardy, its future and exactly how it conducts business will almost certainly be more impacted by the (political) response to climate change than by the climate change itself. The auto industry and climate change are closely coupled — what happens to one affects the other, which makes using separable climate and socioeconomic scenarios somewhat constraining. Other industries are not so much coupled (in a two-way interaction sense) as they are driven (in a one-way forced sense), like the electric industry, for example. What happens politically as a result of climate change will have an impact on this industry (it is responsible for about a third of atmospheric CO₂), but climate change itself, with its periods of extreme weather, will also have an impact. A third type of industry, where climate change will have primarily direct impacts is something like recreation. Water levels and frequency of extreme weather are likely to directly impact how many people go to the beaches or go boating for example.

The US National Assessment contracted NPA Data Services to produce regional socioeconomic projections. The socioeconomic scenarios include basic information about population and wealth and the results are shown in Figure 3.3 [1-7]. Three alternate growth projections, baseline, high, and low were developed, extending over the next few decades. The baseline scenario assumes that the current trends will continue. The high and low growth scenarios were intended to be near the limits of plausibility. All three projections assume a relatively peaceful

world. Population is calculated from births, immigration, and deaths.

National projections for the baseline scenario were based on assumptions about population and follow the latest Census Bureau projections about fertility and mortality. The number of immigrants is allowed to increase at a rate of 1.4 % per year until 2025 after which it remains a constant proportion of the population. The result is a baseline projection with a national population growth rate of 0.87% between 1997 and 2025 and a rate of 0.65% from 2025 to 2050. Additionally a national high growth scenario assumed an open door US immigration policy. The result was a growth rate of 1.18% from 1997-2025 and a growth rate of 1.28% from 2025-2050. Finally a national low growth scenario was generated based on slowing and eventually stabilizing population and very limited immigration. The corresponding low growth rates are 0.41% and 0.20%.

The size of the economy is determined by two variables, employment and productivity in the NPA models. Employment is determined by population and labor force participation rates. Productivity comes from the gross domestic product (GDP) per person. In the national baseline scenario the growth in GDP per person averages 1.26% from 1997-2025 and then to 1.12% by 2050. In the high growth scenario dramatic growth was assumed with productivity allowed to grow by 2.4 % per year from 1997-2050. In the low growth scenario, productivity was slower and eventually virtually stagnant. The rates were 1.23% until 2025 and 0.13% to 2050.

These national projections were converted to regional projections using the Regional Economic Information System (REIS) of the Bureau of Economic Analysis of the US Department of Commerce. The regional projections cover IL, IN, MI, OH, WI, and MN, which is not exactly the Great Lakes region, but is likely sufficiently close to get a sense of a possible trend. The major differences with respect to employment involve the self employed and those employed in the military. These are handled more thoroughly in the REIS database. With respect to the economy, personal income data are used in the REIS database and are available at the county level while GDP is only available at the national level. For the future, employment projections show an increase for most industries from

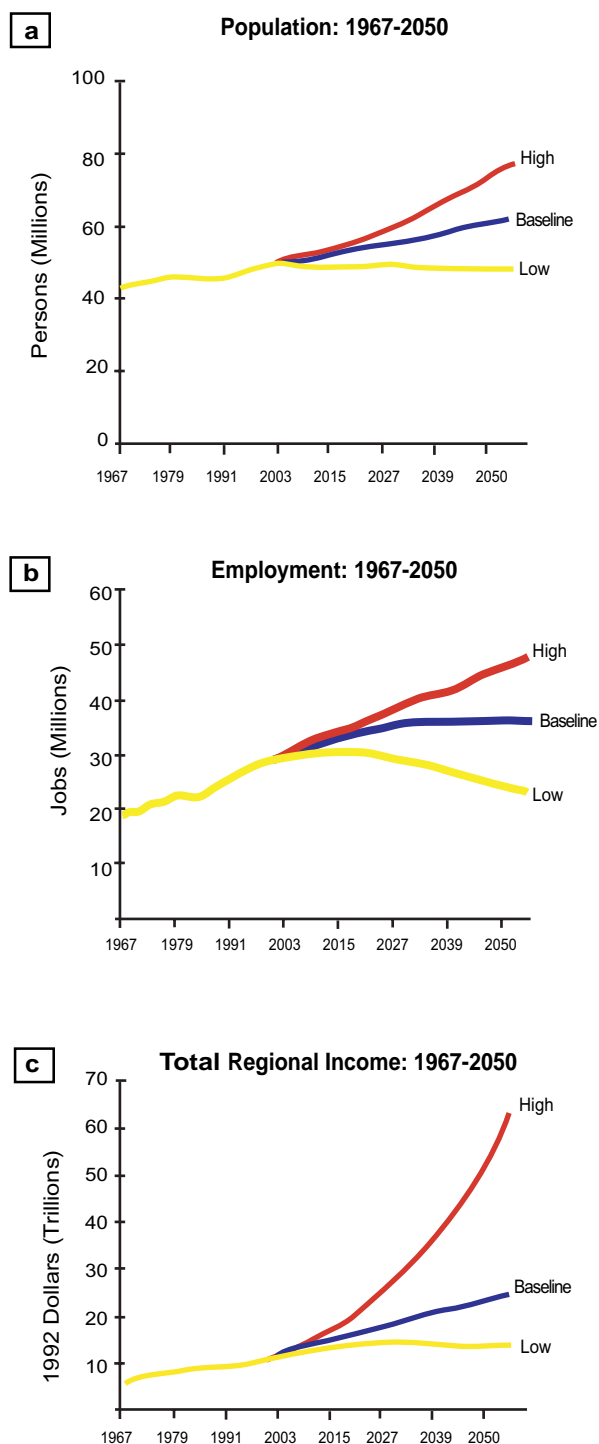


Figure 3.3: Socioeconomic trends for: a) population, b) employment, and c) total regional income for Illinois, Indiana, Michigan, Ohio, Wisconsin, and Minnesota.

an absolute-dollar perspective (Figure 3.4) but decreases in automobile manufacturing and farming and a slight gain in lumber and wood manufacturing from a percentage-contribution perspective (Figure 3.5). Employment in amusement and recreation are expected to increase by approximately 35% between 2000 and 2050.

Year	1967	1990	2020	2050
Farm	13	7	5	11
Forestry and Fisheries	1	3	9	15
Mining	3	3	4	6
Construction	29	39	86	129
Manufacturing	173	185	231	305
Transp., Comm. & Public Utilities	31	43	70	95
Wholesale Trade	27	46	88	127
Retail Trade	50	61	104	146
Finance, Insurance & Real Estate	21	41	102	157
Services	60	157	359	534
Government Activities	52	91	136	191
Totals	425	607	1051	1491
Population	43,006	46,463	53,570	62,097
Income	565,892	940,607	1,698,387	2,483,407
Per Capita Income	13,159	20,244	31,704	39,992

Figure 3.4: Regional (i.e., Illinois, Indiana, Michigan, Ohio, Wisconsin, and Minnesota) economy: Current and future projections for selected industries and four different time periods. (1992 billions of dollars; population in millions) [3-3].

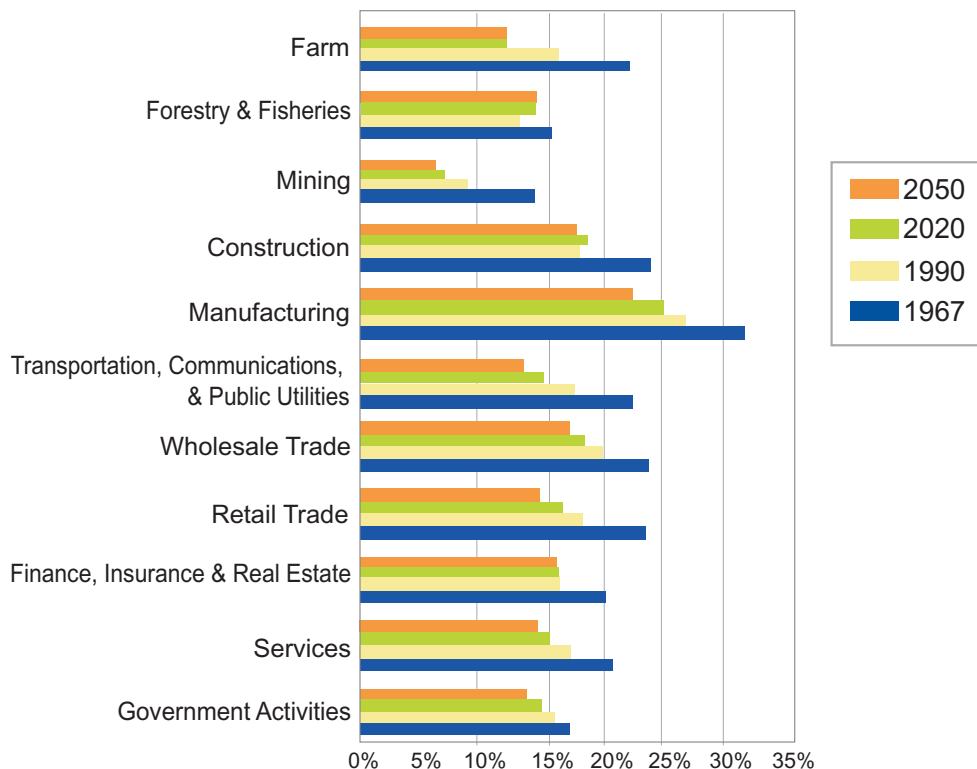


Figure 3.5: Region 3 (i.e., Illinois, Indiana, Michigan, Ohio, and Wisconsin,) contributions (%) to the national total for selected industries and four different time periods [3-3].



FOCUS

CLIMATE CHANGE AND LAKE-EFFECT SNOW

study conducted by

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Lake-effect snow is a common cold season phenomenon in the Great Lakes region, occurring most frequently in late autumn and early winter. This type of snow results from the rapid warming and moistening of Arctic air masses that pass over lakes that are still relatively warm. The Arctic air becomes unstable and the resulting convection forms clouds and precipitation. The precipitation falls over and downwind of the lakes. For very cold air masses, temperatures remain below freezing even after passage over the warmer lakes, causing the precipitation to fall as snow. Lake-effect snow causes considerable enhancement of snowfall in narrow snowbelts along the downwind lakeshores. For example, Detroit, Michigan, on the western (upwind) shore of Lake Erie receives an average of 42 in yr⁻¹, while Buffalo, New York, on the eastern (downwind) shore of Lake Erie, receives an average of 92 in yr⁻¹. Toronto, Ontario, on the northwestern (upwind) shore of Lake Ontario, receives about 54 in yr⁻¹, while Syracuse, New York, located to the southeast (downwind) shore of Lake Ontario, receives 109 in yr⁻¹ and is the snowiest metropolitan area in the United States. The lake-effect snow season typically extends from November through February over all of the Great Lakes except for Lake Erie, which normally freezes over by the end of January, putting an abrupt end to the lake-effect snowfall in places like Erie, PA and Buffalo, NY for the remainder of the winter.

Lake-effect snow creates transportation problems and results in additional costs to keep roads clear. A major transportation artery, Interstate 90, passes along the southern shore of Lake Erie and is vulnerable to lake-effect snow storms. Increased property damage, injuries, and deaths due to accidents and exertion accompany such events. Major airports at Cleveland and Buffalo are also vulnerable to disruptions. The roofs of buildings in the snowbelts must be built to support heavier loads of snow than for locations away from the snowbelts [F3-1]. Retail sales may drop temporarily. A single severe lake-effect snowstorm near Cleveland, OH in November 1996 resulted in 8 deaths, hundreds of human injuries, widespread power outages, damage to numerous buildings, and over \$30 million in economic losses ([F3-2]; S.A.Changnon, personal communication). On the positive side, there is a large private snow removal business sector that benefits from the snowfall. Sales of winter-related products may increase. Lake-effect snowfall also supports an important winter recreational industry in some parts of the Great Lakes. Although there is not a large downhill ski industry in the Lake Erie snowbelt, many of the Midwest's premier downhill ski resorts are located in the snowbelts of the other lakes in the region.

Abnormally light snowfall amounts during the winter season have also created significant negative impacts, particularly when snowfall deficiencies have been widespread and the associated losses have affected many locations throughout the Great Lakes region. Such was the case over most of the Great Lakes region during the 1997-1998 El Niño year. The widespread nature of this event resulted in impacts over a large area. For example, business at Midwestern ski resorts was down 50% and losses were estimated at \$120 million (S.A.Changnon, personal communication).

Recent studies show that past changes in lake-effect snowfall on decadal time frames were related to climatic shifts. For example, lake-effect snowfall on the lee shore of Lake Michigan increased from the 1930s into the 1970s – coincident with a decrease in mean winter temperature [F3-3]. More recently, changes in heavy lake-effect snow events were evaluated as part of the current assessment for the Lake Erie snowbelt. Lighter events certainly occur more frequently and contribute significantly to the total annual snowfall totals, but Great Lakes residents have adapted to them so they are not nearly the societal concern that heavy events are. For the period 1950-1995, all occurrences of lake-effect snowfall in excess of 8 inches at Erie, PA and Westfield, NY were identified. Four surface conditions (air temperature, lake-air temperature difference, wind speed, wind direction) were found to be highly correlated with the occurrence of heavy lake-effect snow, when they occur within certain favorable ranges simultaneously. In the 1950-1995 observational data, favorable conditions occurred approximately 17 times per decade. In the HadCM2 simulation for the 1960-1989 period, favorable conditions occurred approximately 15 times per decade, very similar to the observational record.

The simultaneous occurrence of these favorable conditions decreases from 15 to 7 times per decade in the HadCM2 model between the 1960-1989 and 2070-2099 period. This decrease occurred – even though the lake-effect season was extended through the end of February to account for the fact that Lake Erie would no longer likely freeze over – almost entirely because of a drop in the number of days below freezing. When the simultaneous occurrence of the other favorable conditions was examined, there was very little difference between the 1960-1989 and the 2070-2099 periods. Even the frequency of occurrence of lake-air temperature differences did not change because the lake tem-

perature increased about the same amount as the air temperature. This suggests that the decrease in heavy lake-effect snow may be accompanied by an increase in winter-time lake-effect rain events, which are now most frequent in the autumn [F3-4]. A similar analysis for the Lake Michigan and Lake Superior snowbelts indicates that the southern Lake Michigan snowbelt will experience a decrease in the number of below-freezing days in the late 21st Century similar to the Lake Erie snowbelt, but little change in the other variables. However, for the Lake Superior snowbelt, the mean winter temperature remains below 32°F and there is little change both in the number of below-freezing days and the frequency of favorable ranges of the other variables. Thus, there may be little change in the frequency of heavy lake-effect snow in the Lake Superior snowbelt and a substantial decrease in the southern Lake Michigan and Lake Erie snowbelts. The fact that air-temperature was found to be the primary determining factor in reducing the frequency of heavy lake-effect events in this study suggests that the frequency of light(er) events may be influenced in the same way. Figure F3.1 summarizes the anticipated regional impacts of climate change on lake-effect snow patterns – suggesting almost no change in the northernmost belts but approximately a 50% decrease in southernmost belts. The spatial variability demonstrates that the impacts of climate change as portrayed by the HadCM2 model can be greatly influenced by subtle regional differences. The overall warmer scenario portrayed by the CGCM1 model suggests an even greater reduction in lake-effect snow than was found here.

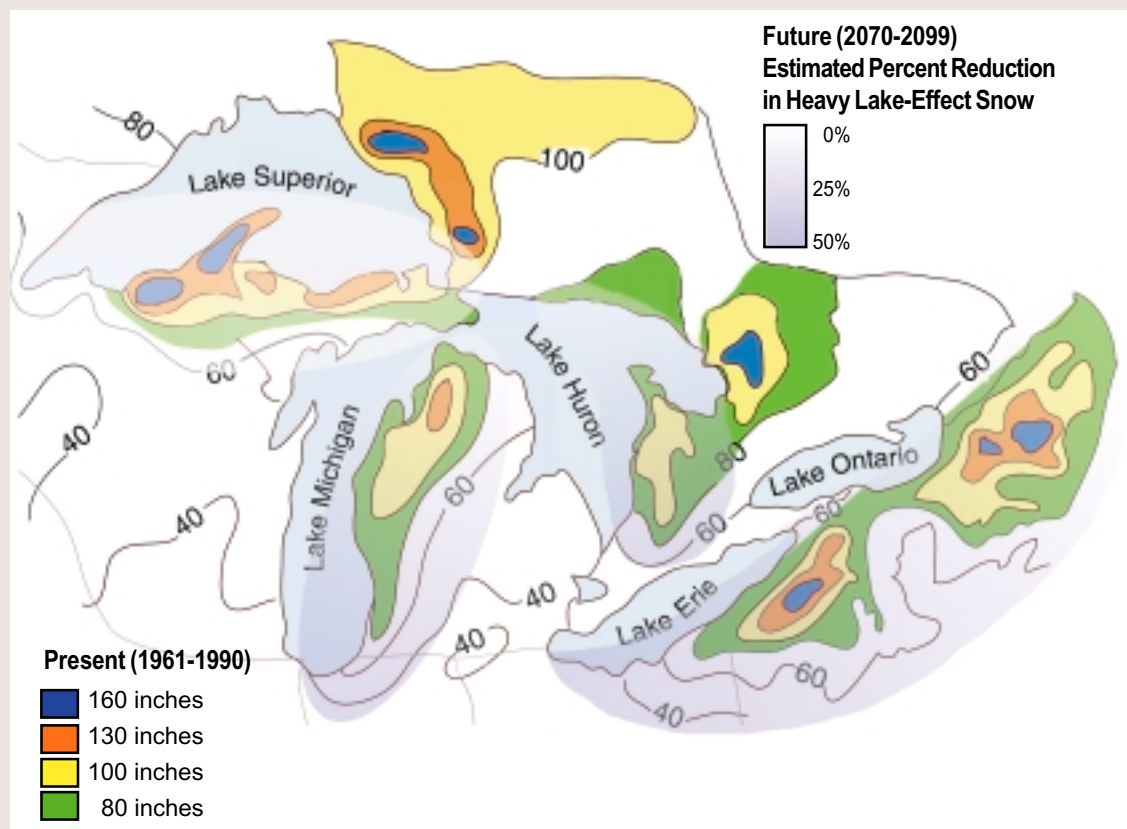


Figure F3.1: Annual snowfall totals, including both lake-effect and other types of snowstorms. Present amounts shown by contours (inches). Areas where the lake-effect causes a sizeable increase in snow amounts are highlighted in color. The impacts of climate change by 2070-2099 on heavy lake effect snow events, as estimated from HadCM2, is shown by the shading. Note that, although the shading covers the entire map, it strictly applies only to the lake-effect snow belts (colored regions) since this study did not look at all types of snow events.

Impacts, Challenges, and Opportunities

4. GREAT LAKES RESOURCES

study conducted by

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The Great Lakes/St. Lawrence Seaway is used for transportation, hydroelectric power generation, and recreation. Hydro-power facilities are located on the St. Marys, Niagara, and St. Lawrence Rivers and at DeCew Falls off the Welland Canal (Figure 4.1). The Great Lakes are also one of the prime recreational boating areas in the country. The three-county area around Detroit has more boating registrations than any other similar-size area in the US. The Great Lakes system contains one of the nation's prime sport fisheries as well as a smaller commercial fishery, representing billions of dollars to the economy. Because the Great Lakes Basin is an internationally shared resource, there are numerous state, provincial, county, and municipal authorities, leading to a complex jurisdictional structure.

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Current Stresses

The Great Lakes have historically enjoyed a relatively small range in lake levels, approximately 6.5 feet from the recorded monthly maximum to the recorded monthly minimum (Figure 4.1).



Figure 4.1: The Laurentian Great Lakes.

ure 4.2). Superimposed upon the average levels are seasonal cycles of 10-12 inches. The lake levels for the past 30 years have been in an extremely high water level regime - the highest in recorded history, due to increased summer and fall precipitation. Record highs were set in 1973 and again in 1986. In 1997, Lake Erie rose again to near record highs. However, over the past year (to March 2000), the lake levels have experienced the second largest decline in about 100 years, second only to that during the Dust Bowl drought of 1931. The lake levels are currently near their longer term (1900-1969) mean. Impacts of the recent drop are being experienced by the shipping and hydropower industries, recreational boaters, and some individual water supplies. Many recreational boaters and marina operators around the lakes consider the current near-average lake levels to represent low-level conditions. The Great Lakes commercial navigation interests can no longer carry the same loads as they have for the past 30 years due to decreased channel depths. Revision of the existing regulation plans for Lakes Superior and Ontario is being requested by some interest groups to maintain lake levels at what they consider more accurate elevations.

There is currently an ongoing debate about the export of Great Lakes water from the basin. If the lake levels continue to decline and the current drought continues, then arguments for interbasin diversion of water into and out of the Great Lakes are also likely to intensify. A coordinated approach to policy development will be crucial for coping with lowered lake levels. The policy implications of long-term lowered lake levels are far different than the major policy deliberations during the past several years, which have emphasized coping with high lake levels. Major policy decisions will have to address the distribution of benefits among commercial, riparian, recreational, and ecological interests, between upstream and downstream interests, and finally among the many jurisdictional interests.

Previous Assessments

A number of 2 X CO₂ equilibrium climate change future scenarios have been developed [4-1, 4-2], showing that increases in

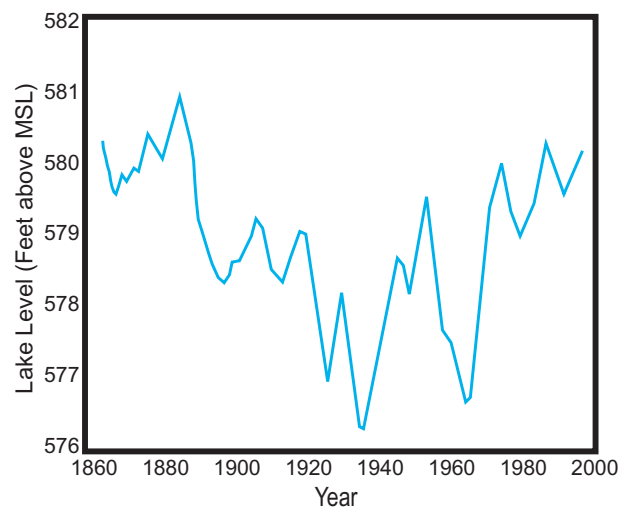


Figure 4.2: Historic Lake Michigan-Huron water levels.

atmospheric greenhouse gas concentration produce a warming effect that enhances evaporation in the Great Lakes drainage basin and over the lakes themselves. Although the general circulation models (GCMs) have produced varying results in terms of change in precipitation (both wetter and drier futures), they have agreed in showing an increase in lake surface temperature, a decrease in basin runoff, and a consequent increase in lake evaporation, resulting in reduced interlake channel flow and water levels on all of the Great Lakes. Average water level reductions ranged from 0.75-8 feet, depending on the lake and the GCM output. These model results suggested that future lake levels could be much lower than those recorded over the past 150 years. These changes would have a variety of impacts on the water resources of the system. For example, these studies showed that channel depths would decrease by 1.6-8.2 feet, necessitating extensive dredging in the connecting channels and the major harbors. In a number of areas the dredged material is highly contaminated, so dredging would stir up once-buried toxins and create a problem with spoil disposal. Lower water levels and flows would greatly reduce access to harbors and marinas, necessitating also extensive private dredging.

Such water level drops would endanger the usability of the Chicago Diversion [4-3]. Since the 1940s, when the Chicago Sanitary and Ship Canal was created by diverting Lake Michigan water to the Mississippi River, the canal elevation has been

maintained at about 2 1/2 feet below the level of Lake Michigan. An extreme drop in the average lake level would dramatically affect the flow of water from Lake Michigan across the divide and to the Illinois River. This would force the Illinois Department of Natural Resources to either reverse the flow in the canal, posing serious health risks, or to dredge approximately 30 miles of the canal system, half of which would entail rock removal at a huge cost to the public [4-4].

Faced with much lower river flows and lake levels, some hydropower plants would be forced to shut down or dramatically reduce power production. Treaty requirements protecting the aesthetics of Niagara Falls would ensure greatly reduced electricity generation there under low flow conditions. Inexpensive, nonpolluting hydropower might have to be replaced by fossil-fueled or nuclear powered plants that would exacerbate the low water levels by increasing the amount of water consumed for cooling.

Current Assessment

Temperature, precipitation, and other atmospheric output from the HadCM2 and CGCM1 scenarios were applied to observed long-term time series as input to a hydrologic model in order to get estimates of future hydrologic changes. The hydrologic model was developed at the Great Lakes Environmental Research Laboratory. It includes lake regulation plans. It was used to calculate lake levels and flows in the connecting channels from net basin water supplies that were computed using output from both GCMs.

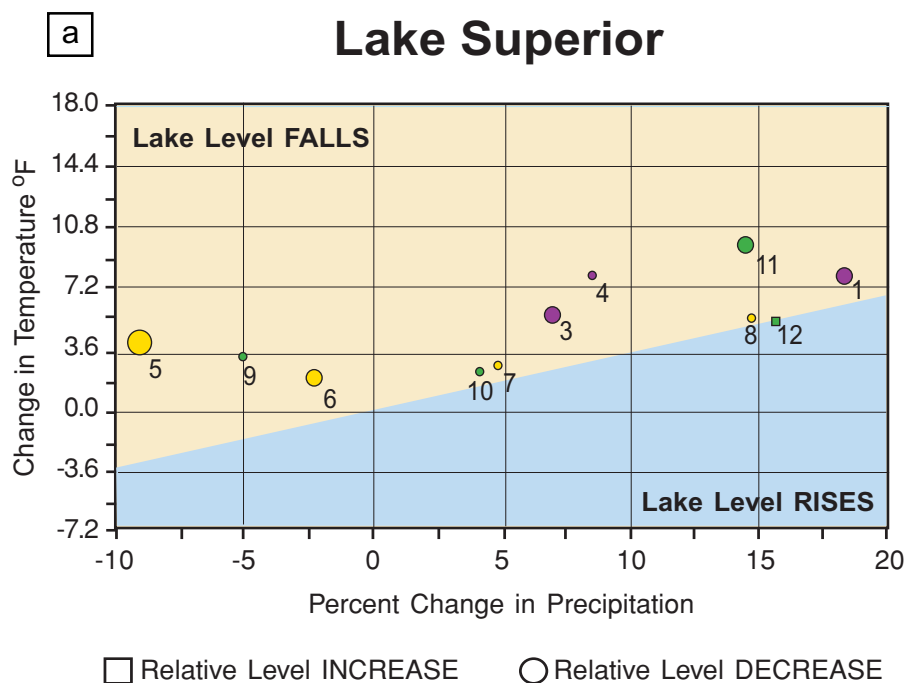
Lake Levels

The climate scenarios presented here depict a wide range in levels and flows for the Great Lakes in the 21st century. The mean annual runoff is reduced considerably by using the CGCM1 output. The reduced runoff, combined with increased lake surface evaporation due to a strong increase in lake surface temperature, yields a reduction in net basin supply (water input to the lakes by runoff from its basin plus input from

overlake precipitation minus output to overlake evaporation) that increases in magnitude with time. Corresponding lake level reductions from 0.7-2.4 feet are predicted by 2030, with greater reductions at later times, (e.g., 2-5 feet) on Lakes Michigan and Huron by 2090. The magnitude of these changes in lake levels is large enough to distinguish them from those from natural variability, except on Lake Ontario. Outflows from each of the lakes were also reduced. Lake Superior shows the smallest impact, dropping by 0.7-1.4 feet over the same time period. Flows in the connecting channels are reduced by 25-33% of base flow.

The mean annual runoff is little changed or slightly increased when using the HadCM2 output. Combined with modest changes in lake surface temperature, the result is little change or a small increase in net basin supply during each of the time periods investigated. The hydraulic routing of its wetter climate results in rises in water levels up to 1.2 feet for Lake Michigan-Huron, but none of the rises on any of the lakes exceed those expected from natural variability. Water levels on Lake Superior remain essentially unchanged. Outflows from all of the lakes also increase by about 5%. Additionally, it should be noted that due to a decrease in the annual mean runoff between 2030 and 2050 into most of the lakes, the water levels in 2050 are lower than in 2030, as are the outflows. This may indicate an artifact in using 20-year averaging periods for the GCM data in developing hydrologic scenarios, as the random variability between 20-year periods appears to exceed the long-term trend forced by greenhouse gases.

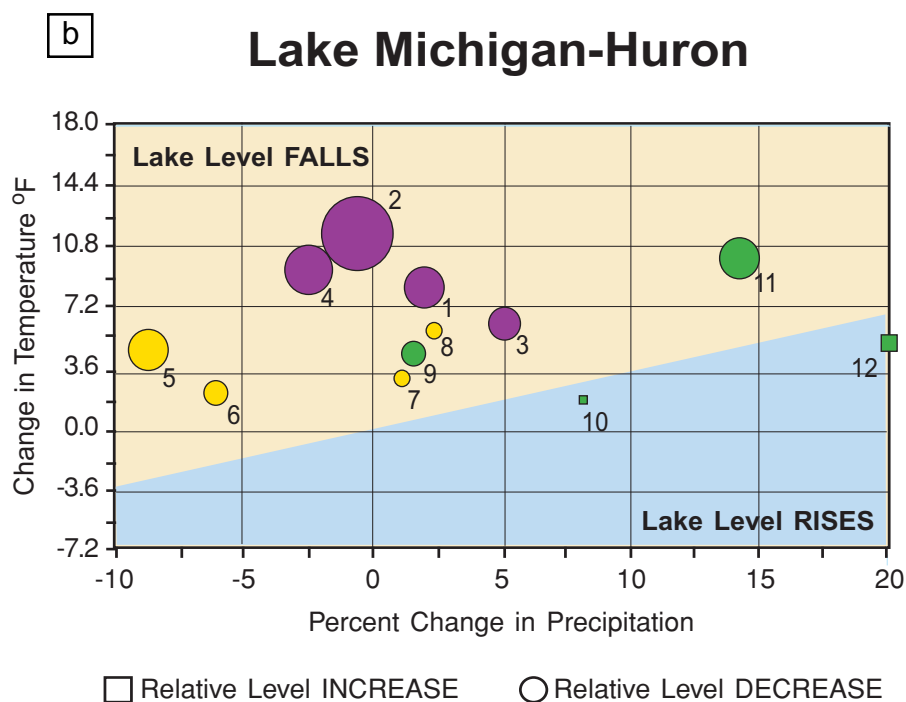
Lake level changes are shown for both the CGCM1 and HadCM2 models for 2030 and 2090, along with results from some previous studies, in Figure 4.3. Lakes Superior and Michigan-Huron were chosen because they are the least affected by changes in upstream conditions. The results from the HadCM2 scenario differ not only from the CGCM1 scenario, but also from those from all other models used in previous assessments, in that the output from all those models also result in lowered lake levels (It should be noted, though, most all of those models used equilibrium $2 \times \text{CO}_2$ — see box on next page).



	MODEL	PERIOD	TYPE	Δ LEVEL
1	GISS	2XCO ₂	E	-1.54
2	GFDL	2XCO ₂	E	failed
3	OSU	2XCO ₂	E	-1.51
4	CCC1	2XCO ₂	E	-0.75
5	MOTR2	2020	T	-2.62
6	CCTR2	2020	T	-1.64
7	GFTR2	2020	T	-0.66
8	HCTR2	2020	T	-0.33
9	CGCM1	2030	T	-0.72
10	HadCM2	2030	T	-0.03
11	CGCM1	2090	T	-1.38
12	HadCM2	2090	T	+0.36

E: Equilibrium model

T: Transient model



	MODEL	PERIOD	TYPE	Δ LEVEL
1	GISS	2XCO ₂	E	-4.30
2	GFDL	2XCO ₂	E	-8.13
3	OSU	2XCO ₂	E	-3.25
4	CCC1	2XCO ₂	E	-5.31
5	MOTR2	2020	T	-4.59
6	CCTR2	2020	T	-2.95
7	GFTR2	2020	T	-1.31
8	HCTR2	2020	T	-1.64
9	CGCM1	2030	T	-2.36
10	HadCM2	2030	T	+0.16
11	CGCM1	2090	T	-4.53
12	HadCM2	2090	T	+0.16

E: Equilibrium model

T: Transient model

Figure 4.3: a) Lake Superior and b) Lake Michigan-Huron comparison from selected climate change studies. The size of the marker is keyed to the magnitude of the change in lake level. The color represents different studies: the lavender ones (1-4) were taken from previous studies at the Great Lakes Environmental Research Laboratory (GLERL); the yellow ones (5-8) were taken from a recent study by Phil Chao [4-9]; and the green ones (9-12) were done most recently – specifically for this assessment.

Clear and straightforward reasons for the relatively cool and wet conditions of the future time periods within the HadCM2 model are unknown. Nonetheless, its disagreement with the other models widens the range of potential outcomes in hydrologic response to greenhouse warming. One difference of the HadCM2 from the CGCM1 model and previously studied models [4-2] is that it includes the presence of the Great Lakes as a water surface with significant thermal inertia. It is doubtful that this is a full explanation of the increased precipitation and lesser increase in temperature, as differences of similar magnitude have been noted on portions of North America remote from the Great Lakes [4-5].

The most notable difference between these results and those from previous climate change studies is the timing of the change in lake levels and connecting channel flows. Many of the previous studies looked at the impact on the basin from a doubling of carbon dioxide in the atmosphere, which would take about 70 years given a 1% annual compounded increase. This study predicts similarly dramatic declines in water levels and flows by 2030, at least according to the CGCM1 scenario.

TRANSIENT VS. STEADY-STATE MODELS

It should be noted that many previous studies used equilibrium models. That is, simplified ocean models were allowed to come into equilibrium with an atmosphere with doubled CO_2 . In contrast, transient models are now being used in which full dynamical ocean models are coupled to an atmosphere with CO_2 content changing in time. The newer, transient, approach effects a delay in warming by bringing the thermal capacity of the oceans into play in the model. The earlier equilibrium doubled CO_2 model runs also do not include the effect of increased sulfate aerosol concentration in the atmosphere.

The different results from the two scenarios emphasizes the necessity of having policies and water management plans that are robust enough to function over a wide range of water supplies, lake levels, and flows. The Great Lakes have just experienced a 30 year regime of extremely high lake levels similar to those projected by the HadCM2 scenario. The impacts of extreme low levels and flows on the people and the environment in the Great Lakes basin are not as familiar to people as the impacts of high levels. Low records were last set in the 1960s and 1930s, too long ago for the impacts to be common knowledge. Because of our recent experience with high level and flows, the focus on impacts in this report are the less familiar low levels. A drop in the levels of Lakes Michigan-Huron of about a meter in 30 years would severely change the nature of that immense body of water. Lake St. Clair and Lake Erie, with predicted drops in average levels of about 2 feet, respectively, would also be impacted greatly. Connecting channel flows will decrease by about 25% by 2030.

Ice Cover

Simulation to assess changes in lake ice cover were limited to three basins of Lake Superior and three basins of Lake Erie; each basin is simulated separately. Average ice duration for the 1950-95 base period ranged from 11 to 16 weeks, similar to the results of an earlier study [4-6]. The CGCM1 and HadCM2 scenarios have reductions in ice duration that range from 1.7 to 6.7 weeks (2030 scenario), 2.3 to 7.1 weeks (2050 scenario) and 5.3 to 11.6 weeks (2090 scenario). The greatest reductions 37 to 81 days occur for the CGCM1 scenario. Simulation to assess changes in lake ice cover were limited to the basins of Lakes Superior and Erie; each basin is simulated separately. Average ice duration for the 1950-95 base period ranged from 11 to 16 weeks. The CGCM1 and HadCM2 scenarios have reductions in ice duration that range from 1.7 to 6.7 weeks (2030 scenario), 2.3 to 7.1 weeks (2050 scenario) and 5.3 to 11.6 weeks (2090 scenario). The greatest reductions 37 to 81 days occur for the CGCM1 scenario.

Average February ice cover for the base period exceeds 50% in area for all lake basins except eastern Lake Superior (42%). Average February ice cover for the 2030 CGCM1 scenario is less than or equal to 31% of its base period averages; for the 2030 HadCM2 scenario it is less than or equal to 75% of its base period average. For the 2090 scenarios (CGCM1 and HadCM2) the average February ice cover ranges from 2 to 11% for the Lake Superior basins and 1 to 29% for the Lake Erie basins. February is ice-free for most winters simulated under the CGCM1 scenario for Lake Erie.

Impacts

The CGCM1 scenario suggests that the lake levels will drop significantly. A one meter (3.28 feet) average drop in Lake Michigan would disable the Chicago Diversion [4-3, 4-4]. Beaches would be broad, but access to marinas and docks would be severely limited. Great Lakes commercial navigation would be crippled. Electricity generation from hydropower would decline as dramatically as the lake levels. Political discussions over costly and environmentally hazardous dredging projects would abound. Thousands of municipal water intakes and wells would have to be moved or extended. The nature of the fishery would be completely altered due to a lack of spawning ground and

warmer water. Native American and Native Canadian populations that depend on the fishery or marshland for their livelihood would be impacted. Locks would have to be re-engineered and channel walls stabilized.

A much different future is portrayed by the HadCM2 scenario. The HadCM2 predicts a slightly warmer and wetter climate that results in higher lake levels and slightly higher connecting channel flows as compared to the 1954-1995 base period. Since the high water levels of 1985-86 set records on all the lakes of approximately 3 feet above average, the effects of high water levels are still very fresh in our collective memory. High levels most directly threaten shoreline property owners. They present challenges for cities and other jurisdictions faced with maintaining sewage facilities, water supply, seawalls, and harbors.

Table 4.1 shows an interest-based regulation model developed for Lake Ontario and the St. Lawrence River [4-7] which was run for six climate scenarios (2030, 2050, and 2090 for both the CGCM1 and the HadCM2). The model uses ten interest satisfaction (IS) relationships and attempts to maximize the collective satisfaction of all interests that use the resource, thus determining the optimum outflow for Lake Ontario. Satisfaction is defined as the degree that conditions are completely ac-

Table 4.1: Satisfaction (%) Values by interest for various GCM scenarios. Satisfaction refers to the degree that conditions are acceptable or unacceptable to interests; 100% being completely acceptable, 0% being completely unacceptable. Environmental factors are considered after all years are evaluated.

Interest	Base Case	CGCM1			HadCM2		
		2030	2050	2090	2030	2050	2090
Lake Ontario Riparians	27.5	11.3	0.6	0.0	26.3	25.5	15.5
Lake Ontario Rec. Boaters	15.2	0.6	0.0	0.0	16.8	17	8.2
Comm. Nav. on Lake Ontario	57.7	20.5	3.4	0.1	61.3	60.4	53.6
Comm. Nav. - Lake St. Lawrence	99.6	100.0	100.0	99.2	99.9	99.9	53.6
Hydropower-International Reach	66.9	15.7	1.4	0.0	75.1	74.1	59.6
Lake St. Louis Riparians	79.0	41.2	24.7	6.5	78.3	77.2	74.2
Lake St. Louis Rec. Boaters	37.6	16.6	8.1	1.3	36.7	35.8	34.5
Hydropower-Canadian Reach	60.2	31.7	11.3	0.7	63.0	63.1	54.1
Montreal Harbour	70.0	9.5	1.5	0.1	63.8	63.1	74.4
Comm. Nav. - Lake St. Louis	83.5	23.9	4.3	0.0	85.4	83.9	89.7
Env. Factors based on levels range	64.7	47.6	42.9	41.9	62.8	62.3	68.1

ceptable (100%) or unacceptable (0%) to an interest. The interest-based model used outflows varying from 110,000 feet³/second (3110 meters³/second) to 350,000 feet³/second (9910 meters³/second), which are more extreme than those within the regulation plan presently used for Lake Ontario, but necessary to handle conditions resulting from the climate scenarios. The minimum outflow value is lower than the period of record (1860-1998) monthly value of 154,000 ft³/s (4360 m³/s) which occurred in February 1936.

The model was able to evaluate both the dry and wet forecasted conditions as shown in Figure 4.4. In the dry case, extremely low levels were experienced throughout the system becoming most extreme in the 2090 scenario. As such, satisfaction values, which are averages over the entire 42-year period (compared to a base of 1954-1995), decreased over time. For 2030, all interests are generally satisfied less than a third of the time. However, for 2090, total dissatisfaction is experienced by all. The extremely low outflows are below the minimum required for hydropower and adequate depths for commercial navigation can not be maintained. In the wet case, the discomfort felt by riparians was offset by the higher satisfaction scores of the

hydropower and commercial shipping sectors in the 2030 and 2050 scenarios. However, the incidence of higher outflows results in spillage of water at hydroplants and also in higher river velocities impacting navigation. In the 2090 case, extensive flooding would occur throughout the system.

Both high and low levels present challenges for those that regulate Lake Superior and Lake Ontario. The outlets of Lake Superior and Lake Ontario are regulated by the International Joint Commission to promote the stability of lake levels and to balance the interests of those affected by changing lake levels. Neither of the computer models currently used to guide regulation decisions was robust enough to handle the extremely low supplies predicted by the CGCM1 model. The lake level and outflows reported in this study were obtained using the upper lakes regulation and routing model, altered in 1998 to permit extreme high or low supplies. The Lake Ontario operational regulation model also needed alteration to successfully run under these low supply conditions. A modified version of the model designed to flow “pre-project” flows below a specified level (74 meters, IGLD 85) was used and performed satisfactorily.

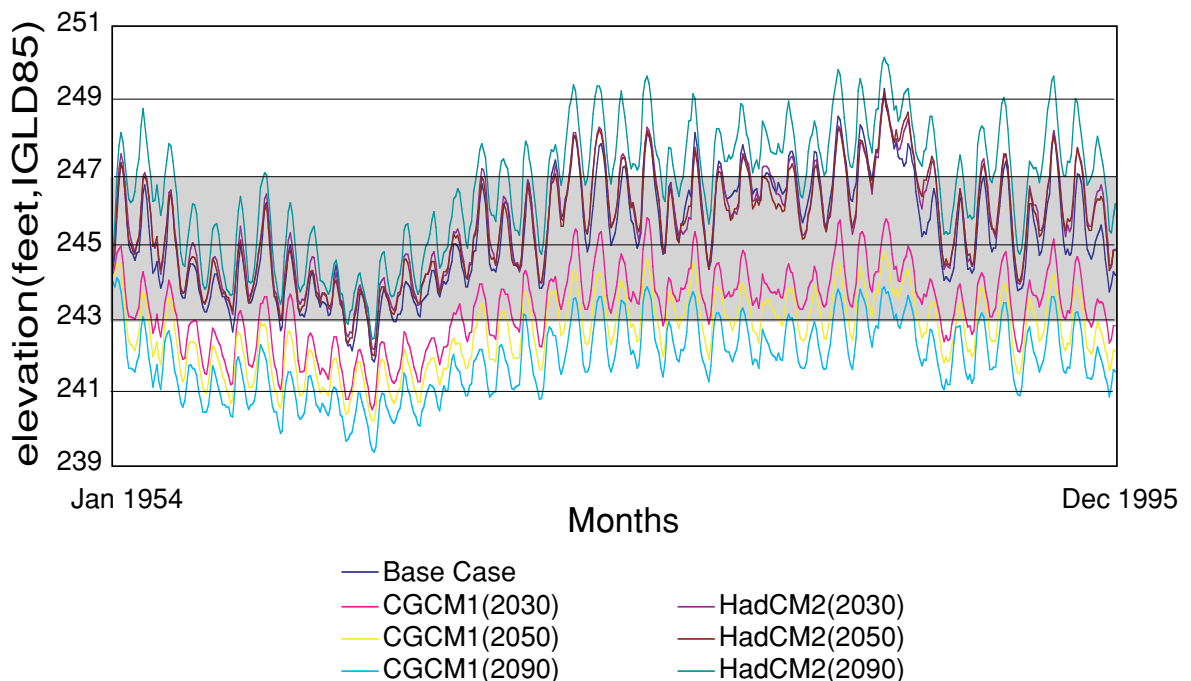


Figure 4.4: Lake Ontario levels using the IS model for various GCMs.

Coping Strategies

The CGCM1 and HadCM2 scenarios have provided two divergent futures on the availability of Great Lakes water resources under climate change. Water resource strategies/policies should be developed which are robust enough to cope with either the high or low water supplies projected for the future by the two models. The relative priorities for various interests must be left to the political process, but all of the interests should be recognized in the development of comprehensive lake regulation plans. In addition, sound public policy has to be determined relative to shoreline development, municipal and industrial infrastructure, environmental considerations, public health, consumptive uses and withdrawals, and other uses of the waters of the Great Lakes.

At a recent binational symposium on climate change in the Great Lakes/St. Lawrence Basin (GLSLB), scientists, politicians, and stakeholders labored to summarize a plan of action [4-3]. All working groups identified a critical need for better communication of any scientific conclusions that have been reached relative to climate change impacts and adaptive responses. Effective communication must be tailored to each of the many diverse audiences that comprise the user community. The public needs to become familiar with probabilistic data in order to understand and react to climate change information. Deterministic forecasts encourage users to focus on the midpoint of the forecast range of levels, often with no knowledge of the risks involved. Risk assessment using probabilistic water level forecasts can contribute to the decision-making process by providing more information to the user about the possible range of outcomes, permitting the user to decide how much risk is acceptable [4-8].

The Great Lakes/St. Lawrence Basin study [4-3] concluded that the issue of climate adaptation will receive little attention until there is more direct involvement of local stakeholders in setting priorities for public action. If the focus is shifted away from

experts' and scientists' views and more toward what climate change can do/is doing to the lives and livelihoods of individuals, then people will be more likely to hear and personalize the message. The messages of the inevitability of change and the necessity of adaptation will be accepted more readily if these are disseminated by established and trusted sectoral organizations than if they come from the scientific community.

Information & Research Needs

More robust regulation models are needed for Lakes Superior and Ontario. The existing operational regulation models for Lakes Superior and Ontario have severe limitations, including failure, when used under climate change conditions. They are primarily based upon economic considerations of the first half of the 20th century and do not take into account such relatively recent interests as the environment and recreational boating. The operational guides currently used for regulating Lakes Superior and Ontario were developed in 1990 and 1963, respectively. However, Lake Superior regulation is primarily based upon Orders of Approval issued in 1914, which used lake levels from 1860-1914.

The ability to translate GCM outputs into Great Lakes basin hydrology and water resource assessments is dependent upon our suite of hydrologic models. Second generation runoff models for the Great Lakes basin watersheds are required to take into account the land surface processes in changing climates as well as changes in land use and cover. These models are required to assess changes in vegetation, evapotranspiration, and runoff due to climate variability and change. Improved lake evaporation models are also required to better assess the changes in lake evaporation under a changed climate. A two-dimensional model that can be run in a forecasting and simulation mode for long time periods is needed. These models will provide better hydrological estimates of climate change which can be used, in turn, to provide input to the social, environmental, and economic sectors impacted by climate change and variability.

Conclusions & Lessons Learned

There have been three significant findings so far that are unique to this study. The first is that using the transient models for the year 2030 shows that significant changes to the Great Lakes water resources could come sooner rather than later. The use of the HadCM2 has also indicated for the first time that there is a potential for slightly higher water levels under climate change. The prior nine model runs for the Great Lakes water resource studies, including the current CGCM1 have all indicated a major lowering of lake levels and a reduction of water supplies. Finally, through the use of the interest satisfaction regulation

model for Lake Ontario, we have the ability to assess impacts on specific interests using a variety of regulation scenarios.

This study reaffirmed that no one method of impact assessment is completely adequate. Many of the shortcomings of our method are noted in this report. It would be very useful to have the National Assessment of Climate Change as an ongoing project, thus maintaining interest and effort in relevant issues, ensuring continuity in research efforts and the development of many alternative methodologies for comparison and increased knowledge on which to base a judgment of the accuracy of the output.





FOCUS

CLIMATE CHANGE AND GREAT LAKES SHIPPING/BOATING

study conducted by

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The Great Lakes region takes its very identity from the lakes. Fishing, boating, and in particular low cost waterborne cargo transportation have shaped the economic activity of the region for centuries. The Great Lakes-St. Lawrence water transportation system supports more than 30,000 jobs in the US and Canada [F4-1]. Business revenue and personal income resulting from the movement of cargo in the system tops \$3 billion/year [F4-1]. Annual shipments (of bulk commodities) average 200 million tons through the 145 ports and terminals. This shipping serves the traditional commodity industries of the upper American Midwest of iron ore/taconite, coal, grain, limestone, salt, and petroleum products [F4-2].

The Great Lakes also teem with recreational boaters – more than 4 million recreational boats are owned within the Great Lakes states. The boating industry consists of boat manufacturers, retailers, marinas, and marine suppliers. Michigan ranks as the top state for boat owners in the United States, with nearly a third of all “boat days” associated with the Great Lakes [F4-2]. Serving these boat owners is a large network of marinas (over 1800 in Minnesota, Wisconsin and Michigan alone).

Impacts from Low Lake Levels

Hydrological processes dictate water levels in the Great Lakes. These levels change on both a seasonal basis as well as a long term basis. Water levels are usually higher in the spring and summer as snowpack water melts and flows to the lakes. Later in the year drier conditions lead to relatively higher evaporation rates and lake levels begin to drop. Fluctuations due to storm events tend to lead to more localized water level changes. Altogether, the Great Lakes Basin represents a complex, interwoven network of waterway resources that are likely to be sensitive to climatic pressures, especially if those pressures result in lowered lake levels.

Current reductions in Great Lakes levels have had a significant effect on both the commercial shipping economy and recreational boating. Starting in the Fall of 1998, lake levels dropped precipitously as a result of the extremely mild 1997-98 winter. With below normal precipitation and above-normal temperatures in 1998-99, lake levels continued to drop below Chart Datum by as much as 6 inches.

Lower lake levels mean ships cannot carry as much. Commercial carriers are very dependent on water depth in channel-ways and harbors. According to the Great Lakes Carrier's Association, a 1,000 foot-long vessel (of the type that is used for intra-lake transportation), loses 270 tons of capacity for each inch of draft loss. Draft is the distance between the water line and the bottom of the vessel. Ocean-going vessels (sized for passageway through the St. Lawrence Seaway), which are approximately 740 feet long, lose 100 tons of capacity for each inch of draft lost. Clearly, in an environment where other modes of transportation (rail and truck) are extremely price-competitive with Great Lakes shipping, the loss of even one-inch of draft can seriously disadvantage Great Lakes carriers and ports.

Low water also makes it more difficult for recreational boaters. There is greater chance of damage when entering or leaving the water. There is greater risk of running aground in harbors, marinas, or while underway in lakes or rivers because of propeller, keel, or hull strikes on lake bottom, boulders or shoals [F4-3]. The most common approach for managing lowered lake level situations in marinas, harbors, and channel-ways is by dredging. Dredging imposes both operational and environmental costs. Much of the material dredged from channels and harbors is contaminated from industrial waste and spills. This must be buried in existing landfills, which are nearing capacity. In the 1970s the Federal Government built 26 Confined Disposal Facilities (CDFs) for dredged sediments of the Great Lakes. The CDFs are viewed as an alternative to the open lake disposal of these sometimes contaminated materials. Currently these 26 CDFs are either full or nearly full, and by 2006 only 2 facilities will have room. Furthermore, ongoing federal support for their continued construction and operation is questionable. In addition, the dredging process releases buried toxins into the lake water. This threatens to reverse the trend towards less contaminated fish in the Great Lakes.

Impacts of Climate Change

The HadCM2 projections are close enough to the status quo to conclude that the socioeconomic impacts of climate change will be minor compared to other pressures that will likely be impacting the regional economy. The CGCM1 scenario suggests an entirely different picture. Namely, significant lake level decreases, ranging from 5 feet for Lake Michigan to 2 feet on Lake Superior. Lake level decreases of this magnitude will clearly have significant effects on the recreation and commercial activities in the region. These effects will be most noticeable in areas like Lake St. Clair, the Detroit River, and The Chicago Diversion as well as numerous smaller harbors, ports and marinas around the lakes (see *Chapter 4: Water Resources* in this report).

The last time that the Great Lakes experienced a significant decline in water levels was during 1962-1964. These declines resulted in dramatic increases in dredging activity and expenditure by the Army Corps of Engineers (the Corps is responsible for 145 harbors and 745 miles of channels in the Great Lakes/St. Lawrence area). Prior to 1963, dredging activity for all of the federal port facilities in the Great Lakes averaged 372,000 cubic yards annually. In the five years after 1963, dredging activity averaged 4,119,000 cubic yards annually. Activity curtailed as lake levels rose in the subsequent 20 years [F4-4].

This tenfold increase in dredging activity is likely to be exceeded in circumstances like those projected by the CGCM1 scenario. During the last five years, average annual dredging activity has removed approximately 752,000 cubic yards. Additionally, costs for dredging have risen significantly since the 1960s. Current prices for dredging are averaging approximately \$8.00 per cubic yard with local highs going above \$12.00 per cubic yard. This implies, that in a situation with heightened demand for dredging services, it would not be unreasonable to assume prices would be at least \$10.00 to \$12.00 per cubic yard on average. Therefore in a situation where 7,500,000 to 12,500,000 cubic yards are being removed from federal harbors on an annual basis, it is reasonable to assume that annual expenditures of \$75-\$125 million could be expected as a minimal investment in Great Lakes shipping infrastructure.

None of these budget figures includes costs to the recreation industry. Already in 1999 dredging frequency has increased for some marinas and small harbors from once every few years to twice per year. In a situation where each harbor needs to be dredged twice per year, the total cost of dredging to the entire industry is significant. For instance, there are 1,883 US marinas on Lakes Superior, Huron, and Michigan. If each of these marinas spends \$15,000 twice per year to dredge, then the total cost of this effort is approximately \$60 million. Annually this would add \$15.00 to the costs of maintaining and operating each of the 4.0 million boats owned in the three state area. Altogether the dollar costs of this type of dredging are significant.

The costs of additional dredging could be partially mitigated by the benefits of additional shipping days on the Lakes caused by less persistent ice cover. Warmer waters would clearly limit ice cover and create opportunities for additional boat movement throughout the whole Great Lakes basin.

Coping Strategies

Because of the environmental costs of handling and disposing of dredge muck, steps should be taken now to site and build a system of new Confined Disposal Facilities (CDFs) for disposing of dredge muck. Regardless of the status of climate change these CDFs are a necessary part of the Great Lakes infrastructure.

One complication to dredging is that some harbors and channels are extremely costly to dredge. The Welland Canal, that allows shipping between Lakes Erie and Ontario, has a rock bottom so deepening it would require a multi-year project including drilling into the rock bottom and blasting away the rock.

Another possible coping mechanism is to transport goods by other means. Waterborne cargo routes are always in competition with rail and truck transportation modes. In recent years waterborne transportation has been losing routes. Railroads that originate traffic inland are reluctant to give up their cargo at the dock. In addition, many destinations are in the interior and require Great Lakes vessels to offload onto rail carriers for the completion of commodity movement. Thus, at one or both ends of many routes, water vessels depend on rail transportation. Railroads can often provide transportation from origination to destination, and have been lowering their prices to capture more market share.

A modal shift from water cargo to rail and truck would have environmental impacts as well. Rail and truck are less fuel-efficient methods and produce more air pollution. For example, wood-and-paper-products used to be transported by rail-ferry on Lake Superior from Thunder Bay, Ontario to Duluth, Minnesota. Now they are transported by rail and truck parallel to the old route. The Minnesota Department of Transportation Ports and Waterways Section estimates the environmental cost from the shift on this single route alone to be \$1.1 million.



5. WATER ECOLOGY

study conducted by

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The Laurentian Great Lakes of North America collectively represent the largest body of surface freshwater in the world, both in terms of area (245,240 km²) and volume (25,310 km³). The lakes represent 20% of the Earth's surface freshwater and 95% of the surface freshwater resources of the United States. They are unique in ecological character, as well as size. They occupy a diversity of ecological settings, from small wetlands nestled in scattered bays to vast ocean-like expanses of deep, open water. The temperatures to which the organisms of the lake are exposed range from the freezing point of water at 32°F (0°C), to upwards of 86°F (30°C) in protected, nearshore areas. Off-shore surface dwellers may experience temperatures between 36 and 77°F (2 and 25°C), while inhabitants of deep basins may only experience an annual change between 36 and 39°F (2 and 4°C). Plants and animals inhabiting the lakes range from wetland species to open water plankton and pelagic fishes of sport and commercial significance.

A climatic warming with higher water temperatures could result in a change in the species composition of the lakes with cooler water species giving way to warm water species [5-1]. Loss of cold, deep-water habitat and stresses caused by low oxygen could contribute to degrading the health of the food web, the fishery it supports and the balance of the entire ecosystem (Figure 5.1).

The fish in the Great Lakes are high on the food chain, so they rely on simpler forms of aquatic life for nourishment, such as algae and invertebrate animals. Algal growth (e.g., primary productivity) in the Great Lakes depends on water temperature, sunlight, mixing, and nutrients such as nitrogen and phosphorus. In winter, the lakes are mixed from top to bottom at temperatures at or below 39°F (4°C) (Figure 5.2a). The mixed water comes in contact with the bottom sediments and the phosphorus and other nutrients contained therein. The low winter sun angle and the short day length reduce the amount of sunlight reaching the lakes and limit photosynthesis and the rate of primary production. The few algal cells that are in the water are mixed to depths greater than that to which the sunlight can reach, so little primary production occurs under these conditions. As spring approaches (Figure 5.2b), sunlight increases and can penetrate to greater depths. When light of

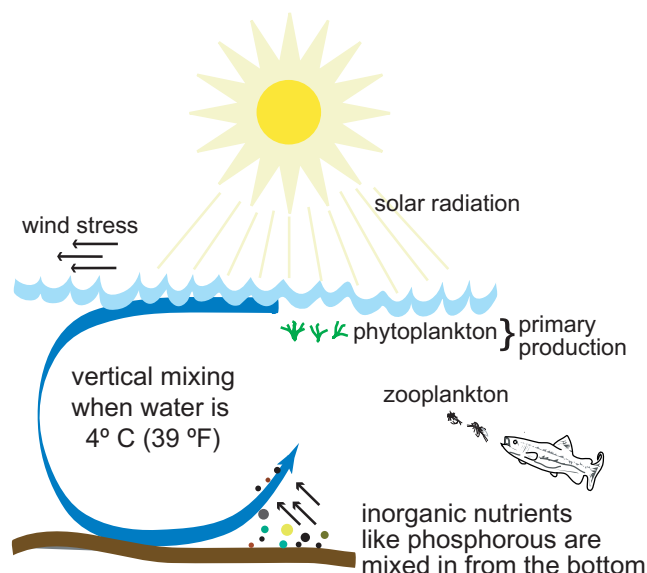


Figure 5.1: Stylized food web of the Great Lakes during autumn to spring mixing period, showing the interaction of climate forcing functions (wind and sunlight) with the chemistry and biology of the ecosystem.

high enough intensity penetrates to a critical depth below the surface, more carbon is fixed by photosynthesis than is consumed by respiration and the algae begin to grow rapidly in what is termed the spring bloom. As long as the water column remains mixed to the bottom so phosphorus may be released from the sediments, and mixed upward into the lighted depths, production will increase the biomass of the primary producers [5-2, 5-3]. As soon as the surface waters warm above 39°F (4°C) thermal stratification sets up and inhibits further mixing to the bottom. At this point, the bloom ceases due to lack of phosphorus, even though light intensities are approaching the annual maximum (Figure 5.2c). In the fall the surface mixed layer deepens and nutrients are again mixed back to the surface. However, now light intensity is on the wane as winter approaches, and only a slight pulse of production occurs (Figure 5.2d).

Current Stresses

Over the years there have been several stresses with which algae, and hence the entire food web including fish and humans, have had to cope. Some of these stresses are biotic, including species invasions by predators, competitors, or pathogens; variations in recruitment success and human intervention by exploitation, such as sport and commercial fishing. Other stresses are abiotic and include excess additions of one nutrients (e.g., phosphorus and nitrogen) as well as potentially toxic compounds (PCB's, mercury, etc.). Fluctuations in water clarity; and variations in cloud cover, wind, temperature, evaporation and lake depth are also potentially important stresses. Climate change acts as a master force on these

latter physical stresses that set the stage upon which the biota must act.

Climate change acts as a master force on each of the stresses. Although the mechanisms by which climate acts on the stresses are complex, there is enough understanding that some linkages can be expressed in quantitative terms. One way to contend with the complexity of biological responses is to evaluate composite biological properties, like biomass or productivity. These composite properties have produced good agreement between prediction and measurement in many applications in environmental science, and so they are good candidates for study under climate change scenarios. Plankton biomass and productivity were, therefore, selected as the biological properties to be examined in this study with respect to the effects of potential future climate change.

Previous Assessments

Previous studies have used output from 2 X CO₂ climate change scenarios to drive temperature, mixing, and nutrient models [5-4, 5-5, 5-6, and 5-7]. General results include increased water temperatures, longer time of warm surface stratification, shallower depth of warming, and more extensive depletion of oxygen from deep waters. Oxygen is typically reduced in bottom waters that are isolated from atmospheric oxygen by thermal stratification. Under these conditions, the respiratory activities of plants, animals and, bacteria consume oxygen that cannot be immediately replaced from above until mixing resumes in the autumn. McCormick [5-6] estimated that under extreme warming conditions, Lake Michigan would not mix thoroughly

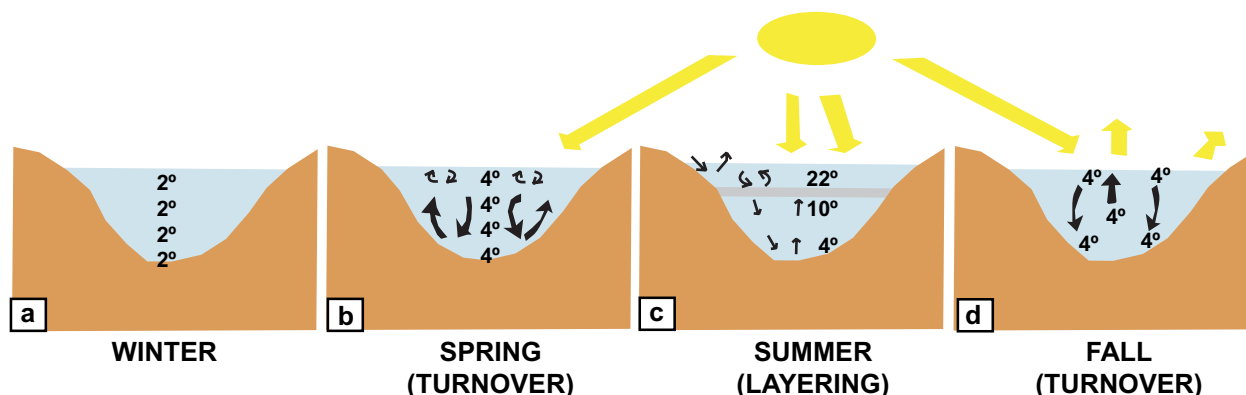


Figure 5.2: Stylized seasonal thermal and mixing cycle in the offshore, non-ice covered areas of the Great Lakes.

during the winter, and that a deep zone could be permanently isolated and become depleted of oxygen.

Other studies have addressed the potential implications for thermal habitats of Great Lakes fish. Magnuson et al. [5-7] studied the potential implications for thermal habitats of Great Lakes fish. They concluded that the size of the habitat favorable for cold-, cool- and warmwater fish would increase in Lake Michigan, but habitats suitable only for cool- and warmwater fish would increase in Lake Erie. Fish yields, estimated from empirical models relating thermal habitat to sustained yields remained about the same for Lake Trout and Whitefish, but increased for Walleye.

Hill and Magnuson [5-8] examined growth of Lake Trout, Yellow Perch, and Largemouth Bass (cold, cool, and warmwater fish respectively) at three nearshore sites in Lake Erie, Lake Michigan, and Lake Superior. Their findings indicate that growth of yearling fish would increase with climate warming if prey consumption also increased, but would decrease if prey consumption remained constant. They noted that changes in growth would be most pronounced in spring and fall due to the projected lengthening of the period of thermal stratification, during which time habitats of differing temperatures are available for fishes that can move to an area with appropriate temperatures for optimal growth.

Estimates of primary production and zooplankton abundance were developed for a 2 X CO₂ climate scenario by Magnuson et al [5-7] based on the work of Regier et al [5-9]. Hill and Magnuson [5-8] report that the ratios of the 2 X CO₂ to 1 X CO₂ scenarios ranged from 1.6 to 2.7 for phytoplankton production, from 1.3 to 2.3 for zooplankton biomass, and from 1.4 to 2.2 for fishery yields. They further note that the actual rates of primary and secondary production in the Great Lakes due to climate warming will depend on a myriad of food web interactions. They state that, "The dynamics of Great Lakes food webs subjected to climate warming must be considered in detail to answer the question of whether increases in primary and secondary production will be sufficient to meet the increased predatory demands of fishes." They concluded that food web dynamics and possible oxygen depletion would, "greatly influence the direction and magnitude of changes in fish growth as

Abiotic Stresses vs. Biotic Stresses

Abiotic Stresses

- variations in solar irradiance caused by day length and cloud cover, because sunlight is necessary for plant growth
- supply rates of essential nutrient elements (e.g., phosphate), because nutrients act as fertilizer for plant growth and for establishment of food webs
- concentrations of potentially toxic compounds (mercury, PCBs, etc.)
- variations in water temperature, because temperature affects the rates of all metabolic processes
- variations in mixing depth, water circulation, and oxygen supply, because oxygen is needed by all higher life forms
- variations in water transparency, because the penetration of light is needed for plant growth, and because visibility affects predator-prey interactions

Biotic Stresses

- species invasions by predators, competitors, or pathogens
- variations in recruitment success and abundance of predators and competitors
- human intervention by exploitation, such as sport and commercial fisheries
- human intervention by artificial stocking of fish at rates or of non-native species that alter the native species and native food webs
- human intervention by alteration of environmental conditions

the climate warms." Hill and Magnuson [5-8] also cite the appendix of a 1989 EPA report in which primary production, zooplankton, and fish yields are projected to increase with climate warming. Nonetheless, they expressed reservations about whether the potential increases would be realized, owing to complexities of food web processes.

There have been few if any specific assessments of the impact of climate change on the primary productivity of the Great Lakes. Assessments have been published for open water and coastal marine waters [5-10, 5-11, 5-12], and studies on the Great Lakes have reported the influence of seasonal and interannual variability in the stressors discussed above [5-2, 5-15], but no integrated assessment exists. The present study attempts to assess the influence of potential climate change on the primary producers at the base of the Great Lakes food web that must be present in great enough abundance to support prey species and any projected increase of fishery yield.

Current Assessment

Existing records of phytoplankton, water quality, temperature, primary productivity, and weather, were used to interpret output from two General Circulation Models (GCMs) and to determine the potential impacts of climate change on primary productivity of free-floating phytoplankton that occupy the open waters of the Great Lakes. Evaluation of the GCM output showed: (1) Both (i.e. CGCM1 and HadCM2) models lead to predicted

increases in the temperature of mixed layers and lake bottom water in all five lakes by as much as 5°C (9°F) during the next century; (2) For each scenario year (2030, 2050, or 2090) the CGCM1 model leads to higher predicted maximum and mean temperatures in the mixed layers, and higher mean temperatures at the bottom of all five lakes, with respect to predictions for the same years using the HadCM2 model; (3) Both models lead to prediction of longer periods of thermal stratification in all 5 lakes; (4) Both models lead to prediction of deeper daily mixing depths during peak thermal stratification than at the present time. The CMCG1 model output generally suggests deeper mixing depths than does the HadCM2 model.

The biological implications of the physical changes predicted by the climate models suggest that: (1) For Lake Erie, no substantial differences in maximum algal biomass would be expected; (2) For Lake Ontario, where peak algal biomass is governed by optical depth rather than by the duration of nutrient limitation, both climate models lead to prediction of modest decreases in peak algal biomass during summer; (3) For Lakes

Scenario	Cloud Cover	Primary Productn.	% BASE MEAN	Stratification Start	Stratification End	Duration
BASE	Mean	122	100	June 13	Oct. 26	135 Days
	Max	117	92			
	Min	132	108			
CGCM1 2030	Mean	107	87	May 13	Nov. 07	177 Days
	Max	98	81			
	Min	115	94			
CGCM1 2050	Mean	105	86	May 01	Nov. 07	190 Days
	Max	97	79			
	Min	113	92			
CGCM1 2090	Mean	100	82	April 05	Nov. 20	225 Days
	Max	93	76			
	Min	107	88			
HADCM2 2030	Mean	115	94	May 31	Nov. 03	155 Days
	Max	106	87			
	Min	124	102			
HADCM2 2050	Mean	114	94	May 28	Nov. 06	161 Days
	Max	106	86			
	Min	123	101			
HADCM2 2090	Mean	108	88	May 05	Nov. 10	189 Days
	Max	100	81			
	Min	116	95			

Table 5.1: Primary production ($\text{g C m}^{-2} \text{ year}^{-1}$) for Lake Michigan for selected model scenarios and current (BASE) conditions. Three sets of cloudiness conditions (Mean, Max, and Min) are shown.

Huron, Michigan, and Superior, the duration of nutrient limitation of algal growth is predicted to increase sharply and thereby reduce primary production.

Looking at Lake Michigan in more detail (Table 5.1), the anticipated changes in the physical characteristics of the lake may impact primary production in two ways, both of which are related to incoming solar radiation. First, altered light intensity, due to an increase or decrease in cloud cover, directly influences rates of photosynthesis. Second, changes in incoming solar radiation change the surface warming and the thermal structure of the lake by extending or retarding the onset and ending dates of stratification. Both GCMs suggest a warming of the lake and longer periods of stratification starting earlier in the spring and extending later into the fall. The “base scenario,” was determined from recent conditions in the lake that

represent the coolest conditions and the shortest periods of thermal stratification. Under the base scenario, the mean date for the onset of thermal stratification occurs on or about June 13 and extends for 135 days through October 26. Using the calculation of Fee [5-14], the mean annual primary production under these conditions is about $122.1 \text{ g C m}^{-2} \text{ yr}^{-1}$. (Table 5-1 and Figure 5.3). These numbers agree well with published values for Lake Michigan [5-13, 5-15].

Calculations of primary production were also run with base biological input parameters, but with projected extreme maximum and minimum percentage cloud cover from the climate models, and the extremes of thermal stratification duration derived in this study. Those values are shown in Figure 5.3 and in Table 5.1 as well. Under the predicted extreme conditions for the year 2090, stratification would be present from April 5

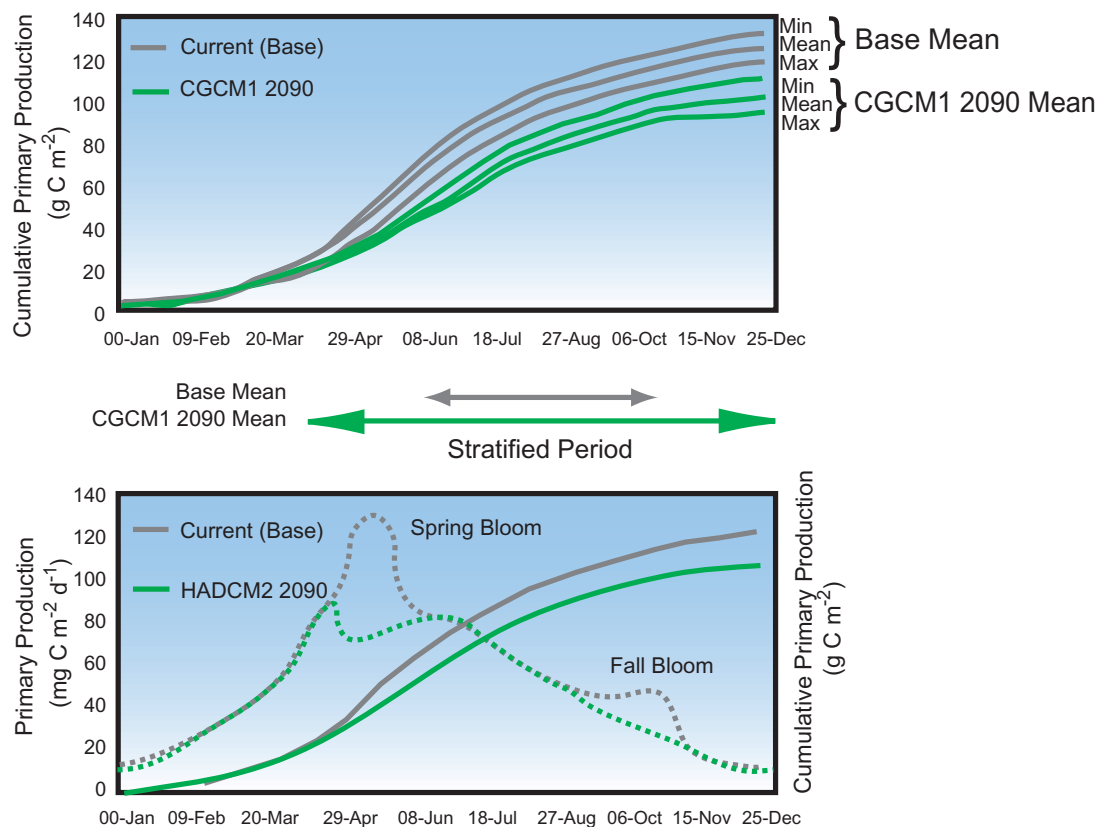


Figure 5.3: Upper: annual primary production for Lake Michigan. Cumulative primary production using current (BASE) conditions and CGCM1 2090 scenario for mean, maximum, and minimum cloud cover, and hence, inversely, mean, minimum and maximum sunlight impinging on the lakes. Lower: Daily (dashed lines) and cumulative primary production (solid lines) using current (BASE) conditions and HadCM2 2090 scenario for mean cloud cover conditions.

to November 20, or 225 days. Estimated mean annual primary production under these conditions was $100.4 \text{ g C m}^{-2} \text{ yr}^{-1}$. Maximum and minimum light conditions produce the expected increase and decrease in production, respectively, while the extension of the period of stratification into the spring growth period tended to truncate the spring bloom and lower the overall annual production by approximately 20% in 2090.

The results of this research suggest that primary production in Lake Michigan will decline as the climate warms. This decline will occur principally as a result of increased duration of thermal stratification that will limit the availability of nutrients in the lighted zone of the lake. When these results are coupled with the projections of Hill and Magnuson [5-8], they suggest if the food web is diminished, then fishery production will also decline. The magnitude of this decline will require more detailed study of the intermediate links in the food web to better understand the complexities of the system. Compounding these predictions are unknowns, such as changes in tributary runoff and nutrient inputs, and the invasion or introduction of new exotic species that could completely change the structure of the food web as we know it today. Such changes have been well documented in the past with the invasion of the alewife, sea lamprey, gobies, zebra mussels, *Bythotrephes* and the stocking of exotic salmon. The effects of climate change alone on the biological productivity of the Great Lakes would appear to be the easiest to predict in the face of unknown invaders and to changes related to politically-driven fishery management decisions.

Coping Strategies

Responses and strategies must be divided into two categories according to whether they apply to the general public or to the scientific community that is involved in the measurements, understanding, and prediction.

The public will likely find that the Lakes are accessible for sport fishing and recreation for longer periods each year than at present. However, the targets of sport fishers will gradually change as the lakes warm and species more tolerant of such conditions move into the lakes.

The Great Lakes are not corn fields to which one can add more or less fertilizer and water, develop heat-tolerant varieties to plant, or keep predators at bay with pesticides in order to maintain a desired state of production in the face of climate change. The lakes are part of a very complex ecosystem that has been altered by the presence of humans. Nutrients and toxic chemicals have been added to the system. Exotic species have been introduced intentionally, or accidentally via ships and canals constructed to support commerce throughout the region. The best response to cope with the projected effects of climate change may be to continue efforts to rebuild stocks of native species that have survived in the lakes through centuries of postglacial change, and to minimize any future degradation of the system by human activities. Attempts to maintain shipping channels and harbors through the regulation of water flows and dredging should strive to minimize impacts on critical habitat required for spawning of native species and the nurturing of young. The projected decline in primary production may require the adjustment of stocking strategies for the sport fishery and appropriate public education programs to explain such changes in light of uncontrolled, external factors brought about by climate change.

Information & Research Needs

The scientific community finds itself with an opportunity to develop and test theory about the Great Lakes ecosystems. The response by this community must be to develop refined, increasingly quantitative and specific predictions that can be tested. It is fair to say that most of the models that are being applied to climate change assessment have significant shortcomings that remain to be discovered and fixed. Shortcomings and erroneous assumptions will come to light only if model predictions are framed in a form that permits them to be proved wrong. Hence, the scientific community must respond to climate change with a strategy that provides predictions on short time horizons, and with an observational program that can detect the strengths and weaknesses of the predictions.

Research will be required to integrate the results of individual projects conducted under the climate assessment program. Critical to our understanding of the food web in the lakes will

be knowledge of future atmospheric precipitation inputs to the lakes and their drainage basin. Information on runoff from the basin and the load of nutrients and sediments carried to the lakes will be needed to adjust production calculations if significant changes in such variables are projected. Projected changes in wind patterns that may alter lake mixing conditions will also be important to have in refining our knowledge of variables forcing the physical state of the lakes. More research will also be needed to better understand the links in the food web between the primary producers and the top, economically important fish in the system.

By assembling the elements needed for this study it became obvious that additional lines of inquiry are required for a comprehensive climate change assessment, including:

- Oxygen dynamics should be incorporated in future models to assess the magnitudes of likely change in that critical chemical property.
- Improved information is needed about the magnitudes and seasonal variation of photosynthetic parameters among lakes. Basic information is needed about rates of respiration in these lakes and variation of the rates with temperature.

- A review is needed to identify the maximum levels of algal biomass sustainable by nutrients in the five Great Lakes.

- Future versions of the mixed layer model should incorporate actual lake morphometry, heat advection by river discharge, and ice dynamics predicted by the NOAA lake evaporation model in order to assess their effect on model predictions.

- Cloud cover changes should be evaluated with respect to the sunlight actually reaching the lake surface.

- Further review is needed to characterize the variation in net intrinsic growth rates of Great Lakes algae and zooplankton with water temperature.

- Future climate predictions should be developed in a probabilistic context by using known interannual variance in meteorologic variables to develop a family of extreme events that would strengthen the validity of longer-term climate-coupled projections.





FOCUS

CLIMATE CHANGE AND RIVER FLOWS

study conducted by

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The 200,000 miles (~325,000 km) of rivers and streams in the Upper Great Lakes (Minnesota, Wisconsin, and Michigan) region contribute significantly to the region's multi-million dollar tourism industry. The Au Sable River is world renown as a recreational fishing "spot" in Northern Lower Michigan. Still, these waters provide more than just places to relax and fish. They provide important goods and services to the 18 million people of the three-state region. They provide water for drinking and for hydropower generation. They provide highly desirable riverfront property. They provide an important ecological role – many species occur primarily or exclusively in these river corridors that act as critical links between forest fragments. For example, the world's last known population of the white catpaw pearly mussel (*Epioblasma obliquata perobliqua*) is found in Fish Creek, which is a small tributary of the Maumee River in Indiana and Ohio. The copper redhorse (*Moxostoma hubbsii*) is a fish whose world distribution is limited to the lower Richelieu River (which drains Lake Champlain) and the adjacent St. Lawrence River.

Current Stresses

Over the years, Great Lakes rivers have been subjected to numerous stresses. For example, the logging era resulted in cleared land, which led to warmer streams and increased sedimentation, which was further exacerbated by floating the logs to river mouths. Today, Grayling, Michigan, is a popular recreational destination, but its namesake, a salmonid fish much sought after by fly-fishers in Alaska and Canada, was extirpated early in the 1900s. Other types of habitat destruction, invasions of non-native species, and chemical pollution are amongst the most important current stresses. Agriculture and sprawl are common examples of how changing land use and population can influence the delivery of sediments, nutrients, and contaminants into surface waters. Climate change will add yet another stress.

Impacts of Climate Change

Assessing the impact of climate change on streamflow is complicated because of the anticipated competing effects of climate change. The wetter conditions that are expected by the end of this century could increase streamflow. But the warmer conditions that are expected could increase evaporation and decrease streamflow. Additionally, vegetation may increase, further increasing transpiration from plants – particularly in the summer. The diverse hydrogeography of the region also has to be considered. Figure F5.1 shows that rivers at the northward limit of the region are primarily snowmelt-driven

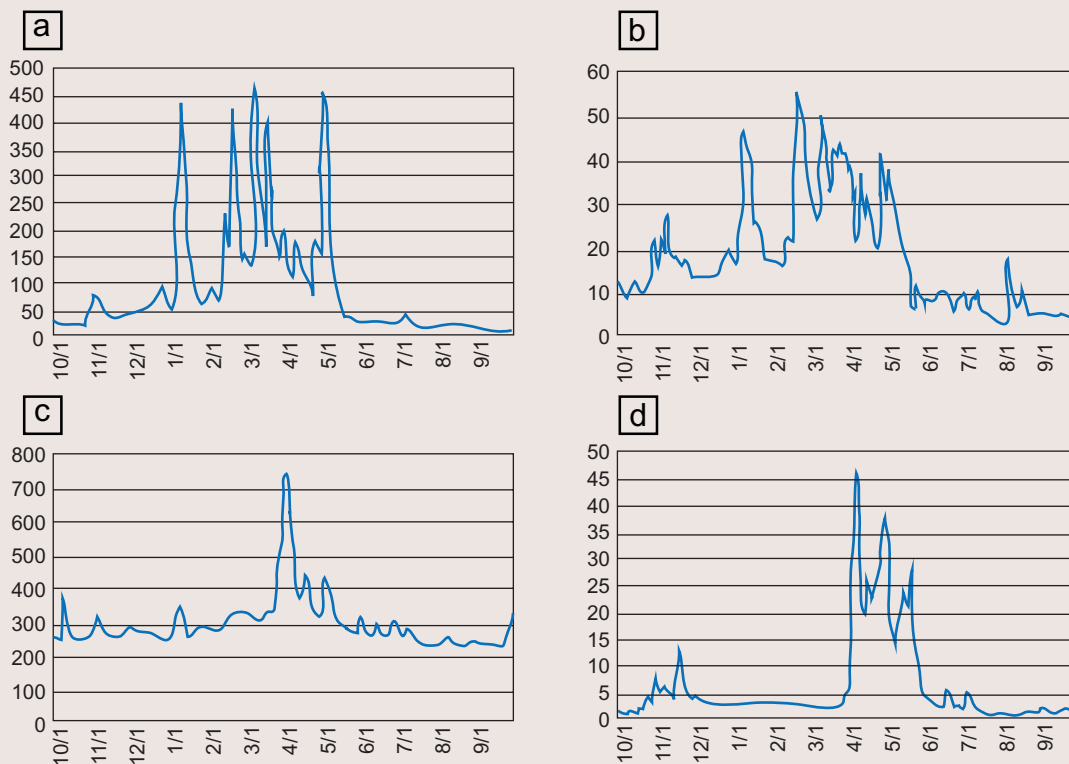


Figure F5.1: Annual hydrographs of four river types characteristic of the Great Lakes region. a) Snowmelt and rain driven stream flow; b) Perennial event-responsive streamflow; c) Perennial, super-stable streamflow; d) Snowmelt-driven streamflow.

(e.g., Sturgeon River), while farther south, rivers exhibit a combination of snow-melt and rain-driven streamflow (e.g., Red Cedar River). Other heartland streams exhibit perennial runoff (e.g., Huron River).

Stream-Flow Patterns and Temperatures

Despite these competing effects and complexities, it is likely that seasonal streamflow patterns will be strongly affected. Peak flows in the upper Midwest will likely occur earlier in the year, because of warmer winters and increased winter runoff. Summer baseflows may be lower, because of increased evapotranspiration, especially during dry years. A large number of rivers in west-central Canada have exhibited earlier spring runoff, particularly in recent years [F5-1]. Seasonal changes in streamflow may be considerable, particularly in the most northerly locations. An expected increase in the frequency and intensity of heavy precipitation and drought events will translate to greater variability in streamflow, which in turn will influence river ecosystems [F5-2].

Stream water temperatures will also likely increase because they are primarily determined by air temperatures. But, they will exhibit considerable local variation due to shading, the interconnection of rivers with lakes and wetlands, and the extent of groundwater supply [F5-3]. Warming effects will be greatest for rivers which have little riparian shading and which receive lesser inputs of groundwater. A study of summer maxima in small tributaries of the River Raisin, southeastern Michigan, reported a surprisingly large range of temperatures, from 73-102°F (23-39°C) [F5-4]. Statistical analysis indicated that if riparian shade was restored, then summer maxima would not exceed 84°F (29°C).

Biological Diversity

The elevated stream temperatures will have complex effects on the biota of rivers. Biological production in aquatic ecosystems increases logarithmically with temperature, and so higher overall productivity might be anticipated. Rates generally increase by a factor of 2-4 with each 18°F (10°C) increase in water temperature, up to about 86°F (30°C) [F5-5]. Other studies reported macroinvertebrate production to increase 3 to 30% for each 1.8°F (1°C) increase in temperature, based on a survey of 1,000 stream studies at mid to high latitudes [F5-6]. However, complexities associated with food webs, along with changing species composition, possibly including non-native invasions, render speculative any predictions of higher productivity. Range shifts will also likely occur. Species extinctions and extirpations will occur at the southern limit of species ranges. Ranges are expected to extend northward if dispersal corridors and suitable habitat are available. Some studies suggest that a 7.2°F (4°C) warming would shift the center of distribution for aquatic invertebrates northward by about 400 miles (640 km). [5-7]. An increase of 7.2°F (4°C) in air temperature should move the simulated ranges of smallmouth bass and yellow perch northward in Canada by about 312 miles (500 km). A national analysis of the change in habitat availability for cold-, cool, and warm-water fishes predicted significant loss of suitable thermal habitat for all three groups [F5-8]. Only a few species of warm-water fishes benefited in these simulations. Fish diversity in the streams and rivers to the south of Michigan, Wisconsin, and Minnesota is considerably higher than in the heartland region [F5-9]. Using the widely quoted figure of a northward shift of 312 miles (500 km) in species distributions with a 5.4°F (3°C) warming, biological diversity of heartland rivers is expected to increase, as more diverse fauna south of the heartland disperses northwards.

While higher ecosystem productivity and greater biological diversity are long term expectations, the shorter-term (decadal to 100+ year timeframe) expectation is uncertain. Dispersal opportunities, habitat suitability for poleward-dispersing species, and changing biotic interactions as consequences of changing species assemblages raise the possibility that both productivity and diversity may be adversely affected. Biotic interactions are likely to be altered by shifts in community species composition, with difficult to predict consequences. At least initially, climate change may benefit a small number of species because of temperature tolerance, dispersal capabilities, or general adaptability. Acting as competitors or predators, those species that initially benefit from climate change may severely impact other species already stressed by changes in temperature and streamflow.

The availability of suitable north-south dispersal routes complicates the response of the biota to climate change [F5-10]. The rivers of the heartland region fall within three great river basins of North America: the Mississippi, the Nelson, and the St. Lawrence including the Laurentian Great Lakes. Invasion by the rich fish fauna of the Ohio region into the Laurentian Basin is impeded by land barriers. Likewise, faunal dispersal from the Mississippi to the Nelson drainages is unlikely to occur naturally. However, the north-south orientation of the Mississippi and St. Croix drainages suggests that dispersal in response to climate warming should occur relatively easily. Humans accidentally and purposefully introduce species into new habitats, and this may result in a leap-frogging of natural barriers. The Calumet River, whose flow was reversed for sewage disposal, now forms a water connection (the Chicago Sanitary and Ship Canal) between the Mississippi and Laurentian Basins, and evidently allowed zebra mussels to invade the Mississippi system. Man-made canals, bait-bucket transfers, and stocking by private individuals and public agencies all may enhance trans-basin dispersal.

Coping Strategies

Hydrologic regime is altered by changes in land use as well as by dams, diversions and other direct modifiers of flow. Societal decisions regarding instream structures and land use can increase or minimize the impacts of climate change. Coping and adaptation strategies include changes in dam management (including flow management and dam removal) and in land management (including conversion of land use and management of streamside or riparian zones). Those rivers linked to lakes, reservoirs and wetlands, fed by quickflow, and with minimal riparian vegetation will experience greater change in water temperatures than will shaded, groundwater-fed rivers with few connections to standing water. Management of riparian vegetation and of human activities that affect quickflow (e.g., farm and city drainage systems, impervious surfaces) are important coping and adaptation strategies.

Over the long term, the biota is expected to change to reflect altered flow and temperature characteristics under future climates. Productivity and diversity both may increase, and anglers will find different sports fishes in their favorite locations. In the short-term, however, rates of dispersal and colonization may lag considerably behind rates of climate change. Local fisheries may experience decades of decline before re-equilibrating. Given the high value of sports-fishing in the Heartland region, local economic effects are likely to be considerable. Ecological science does not presently have the capacity to manage entire ecosystems. Following guidelines of adaptive management, fisheries managers will need to experiment with management practices to cope with changing ecological conditions.

6. LAND ECOLOGY

study conducted by

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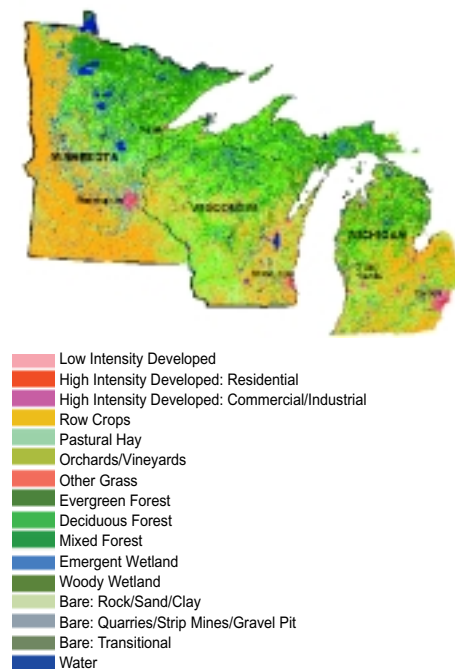
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The natural ecosystems of the Upper Great Lakes region (Michigan, Minnesota and Wisconsin) are characterized by two climate-related gradients. First, there is a southwest to northeast gradient from prairie to forest in Minnesota. The prairie-forest border consists of transitions from short grasses to tall grasses, to oak savanna and forest, which is largely a function of moisture availability. Second, a shift occurs from boreal species (spruce-fir) in the north, to more maple, beech, birch and oak-hickory in the south due to climate and soil gradients. This gradient, occurring in Michigan and Wisconsin, corresponds with a steep south to north land-use gradient from predominantly agriculture to predominantly forest. Figure 6.1 shows most of these features, although some of them are more difficult to identify because of the superimposed land-use (e.g., row crops are planted over areas covered by prairie).

The Upper Great Lakes region had about 42% forest land — more than 52 million acres — in 1992. Moreover, the second and third-growth forests are now maturing, and recent inventories report an increase in the amount of forested land and in stocking on those lands. These forests are immensely important economi-

cally for the region. Over 90% of the forest land is used for commercial forestry, and more than half of the commercial forest land is owned by the nonindustrial private sector [6-1]. The forest sector employs over 200,000 people and generates \$36.7 billion per year of economic activity (\$24 billion per year for forest products alone), which accounts for 3.7% of the total economic activity in the region (Table 6-1) [6-2]. Products include pulp and saw log production, cabinet grade lumber sales and manufacturing, and production of wood products like oriented strand board and specialty items.

In addition to their commercial value, forests contribute greatly to aesthetics, ecosystem biodiversity, quality of life, clean air and water, and reduction of soil erosion in the region. Resi-



*Figure 6.1: Land Cover/Land Use – Midwest Study Area.
Source: National Land Cover Data (NLCD) Landsat
Thematic Mapper Data, 1988-1994.*

dents in the Great Lakes region, like many other Americans, express a desire for these non-commodity values. Places like the Boundary Water Canoe Area in Minnesota, the Upper Peninsula in Michigan, and the Southern Shore of Lake Superior in Wisconsin are frequented by many who appreciate the aesthetic beauty that forests provide. Even the (densely-populated) urban areas have significant tree cover, like the Twin Cities in Minnesota with over 50% tree cover, promoting pride and a sense of well-being to the residents of the region.

The emphasis on non-commodity values often conflicts with the dependence of rural landowners on forests for employment and community development. While both standing volume and demand for forest products continue to increase in the Upper Great Lakes region, the amount of land available for timber production continues to decrease due to conversion to urban and industrial uses, and development of seasonal and retirement homes.

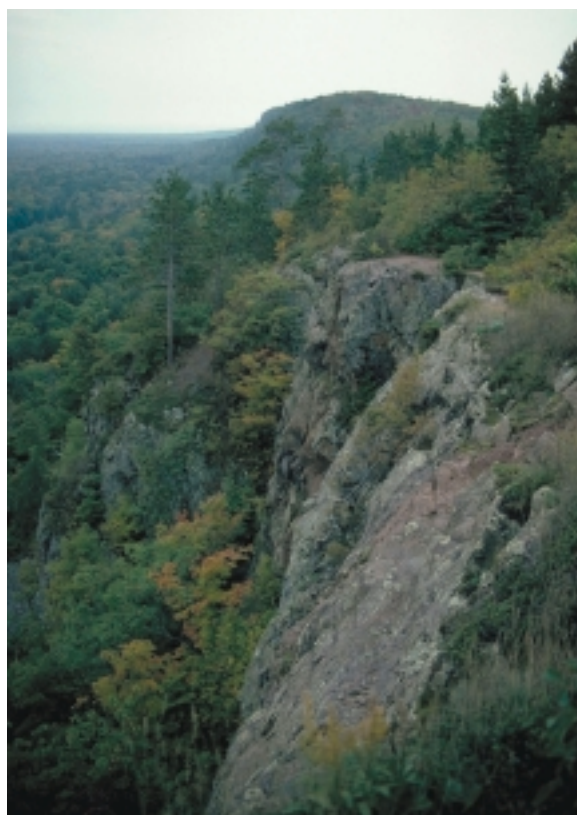


Figure 6.2: Porcupine Mountains escarpment; Lake Superior, Michigan, Source: Michigan Sea Grant Extension, Carol Y. Swinehart.

State	Forested Acres (1,000s)	Portion of Total Land Use (%)	Annual Revenues (1,000s)
Michigan	19,300	53.0%	\$ 9,000
Wisconsin	16,000	46.0%	\$ 19,700
Minnesota	16,700	33.0%	\$ 8,000
Total	52,000	42.7%	\$ 36,700

Table 6.1: Forest related economic activity for Great Lakes region. Source: (MI, WI, and MN Departments of Agriculture in conjunction with USDA, 1998).

Current Stresses

The forest resources of the region are under attack, even without the potential for increases in temperatures caused by climate change. Dutch elm disease contributed an almost complete dieoff of this species throughout the region in the 1970s. Foresters, particularly in the urban areas, used this as a lesson to promote diversity among the species that are planted in cities.

Currently, gypsy moth related defoliation exists and is clearly worsening in all parts of the region. State authorities are aggressively seeking to combat this infestation with ground and satellite-based surveys, biological controls, and trapping methods. Without these efforts, the spread of this infestation would be even greater. Oak wilt is another disease that exists in many parts of the region, although it mostly affects the northern portion. State environmental authorities are working with local communities to suppress the spread of infection. Activities like the development of a model ordinance for the purpose of oak wilt control in Wisconsin and the implementation of a federal oak wilt control program in Minnesota have raised the profile of this disease and have been effective at limiting its spread. Other forest-related diseases and pests that are found in the region in non-epidemic numbers include spruce budworm, cankerworms, forest tent caterpillar, white pine blister rust, white pine weevil, basswood thrips, butternut canker, and asian longhorned beetle.

Extreme weather certainly plays a role in regional forest destruction. Severe storms with lightning, high winds, hail, or tornadoes can quickly destroy whole stands of trees. Recently thinned or logged areas and older forests, from which fire has been excluded, are particularly susceptible to destruction in these circumstances. Exceptionally cold or hot (and dry) weather can also retard growth or kill trees depending on the duration and location of such weather.

Land use is also a serious stress. Although farmland decreased by 5% (according to the Census of Agriculture) between 1987-1997 and forest cover increased by 3% (according to the USDA Forest Service) between 1980-1993, these trends are not likely to continue for long. Increasing development, coupled with declining rates of agricultural abandonment, are likely to lead to declines in forest area in the long term [6-3]. Furthermore, large-scale management of forests on private lands is becoming increasingly difficult as ownership is becoming increasingly fragmented into more and smaller parcels [6-4, 6-5]. During the 30 years between 1960 and 1990, average private parcel sizes declined by an average of 1.2% per year across the region. This parcelization process is related to development of recreational and seasonal homes, but does not necessarily result in forest clearing. It does, however, affect the management of forests and, therefore, the ability of foresters to respond to changing climatic conditions.



Figure 6.3: This rural residence in upper Michigan is emblematic of the kind of development underway throughout the region, whether for seasonal, retirement, or permanent homes; photo by: Daniel G. Brown.

Previous Assessments

Previous modeling efforts that have addressed the impacts of climate change on forests in the Great Lakes region [6-6, 6-7, 6-8, 6-9] have consistently projected a northward shift in species ranges. Most of these efforts have shown that species at the southern boundaries of their ranges, like boreal species within the region or northern hardwood species in the southern part of the region, will experience increased mortality and will be eventually replaced by species from communities to the south. Although there is no general agreement on the time that it will take for this replacement to occur (a very important question), the models are in general agreement about the northward shift in ranges. Mortality, disturbance, migration rates, pests, disease, landuse and management will play a critical role in forest health and composition in the coming decades. To date, only a few of the more advanced dynamic or *transient* analyses of climate change and tree species (migration) have been conducted [6-5]. Many more *steady-state* analyses have been performed [6-10, 6-11]. The steady-state analyses, although easier to design and run, simulate current and future climates separated by a sudden and unrealistic jump in CO₂.

The timing of replacement (e.g., the *transient* nature) is critical because dieback of northern species could occur from heat or drought stress, increased winter damage due to diminished dormancy, or increased pest activity, before the southern species are available for replacement. This possibility raises questions about just how susceptible the forests are to increased mortality, how disturbance regimes will be affected by climate change, and how quickly the southern species can migrate. Other questions relate to the possibility that established trees may persist longer than shown in early studies. Confounded with these questions is the possibility that CO₂ enrichment, by improving water use efficiency by trees and increasing productivity, could speed the succession process.

To evaluate long-term productivity, many studies have assumed that atmospheric CO₂ concentrations continue to increase to

four times the present value over a period of 200 years. One such study focused on the natural productivity that was simulated at four sites – two in Michigan and one each in Minnesota and Wisconsin – using a forest growth model called FORENA [6-8]. Because of the simulated “dieback phenomenon” the sites experienced a total biomass reduction between 15-30%, with the most dramatic dieback occurring on the Michigan sites. After about 300 years of simulation, and a quadrupling of CO₂ in the atmosphere, biomass returned to original levels or slightly higher. The forest community compositions, however, were modified, generally through replacement of boreal forests by northern hardwoods and southern parts of the northern hardwood forest by eastern deciduous forests.

Current Assessment

The current assessment focused on (1) predicting climate change-induced shifts in equilibrium tree species ranges, (2) comparing effects of land-use and climate change on vegetation community distribution and productivity, and (3) evaluating economic impacts of climate change on the forestry industry.

Predicting Shifts in Tree Species Ranges and Climate Change on Vegetation

Future ranges of ten economically valuable tree species were predicted using the STASH model [6-12]. This model has been used to predict range shifts under future climate conditions of northern Europe [6-13]; this is its first application in North America. The model predicts the geographic location of suitable climate space using climate parameters of known physiological significance. Maximum tolerated summer temperatures was added for this study.

Only the output from the CGCM1 model was used, because cloudiness patterns in the HadCM2 model were found to be inconsistent with other output from that model. Model biases were accounted for by adding the difference between future and cur-

rent (e.g., 1994-2003) climate model output to current observations [6-14] for each decade examined.

Four categories of tree responses were found. The first category, which includes black cherry and black walnut, is composed of trees that are presently confined to the southern part of the region, and are predicted to expand northward (Figure 6.4). By the end of this century they should be able to grow successfully throughout Northern Minnesota and Michigan. The potential range of black walnut will also expand toward the eastern part of the region along the southern shores of Lakes Erie and Ontario. Prasad and Iverson’s [6-11] current range limits (using a different data set) show black cherry as already present in Northern Minnesota. They predict some westward expansion into the prairie for both black cherry and black walnut. However, they do not predict northward expansion and they show black walnut as disappearing from the Illinois region – results quite different from those from the STASH model in this assessment.

The second category, red oak and sugar maple, includes trees whose range limits within the Great Lakes region are not greatly affected, but which may show signs of stress in some areas. It is predicted that red oak will persist within its present range, expanding a few tens of kilometers westward into present day prairie. Toward the end of the 21st century warm conditions in summer will begin to stress this species in the southern part of the region. Soil moisture deficits near the limit for this species will stress populations in the lower peninsula of Michigan throughout the century.

Sugar maple will also be stressed by limiting soil moisture in Lower Michigan. However, in the last decade of the 21st century, it is predicted that sugar maple will begin to grow into regions of Minnesota that were formerly prairie. In contrast, Prasad and Iverson [6-11] predict a strong limitation or elimination of this species throughout the region. Only their predictions using GISS show any sugar maple persisting in the Great Lakes region (in Northern Minnesota). Davis and Zabinski [6-9] pre-

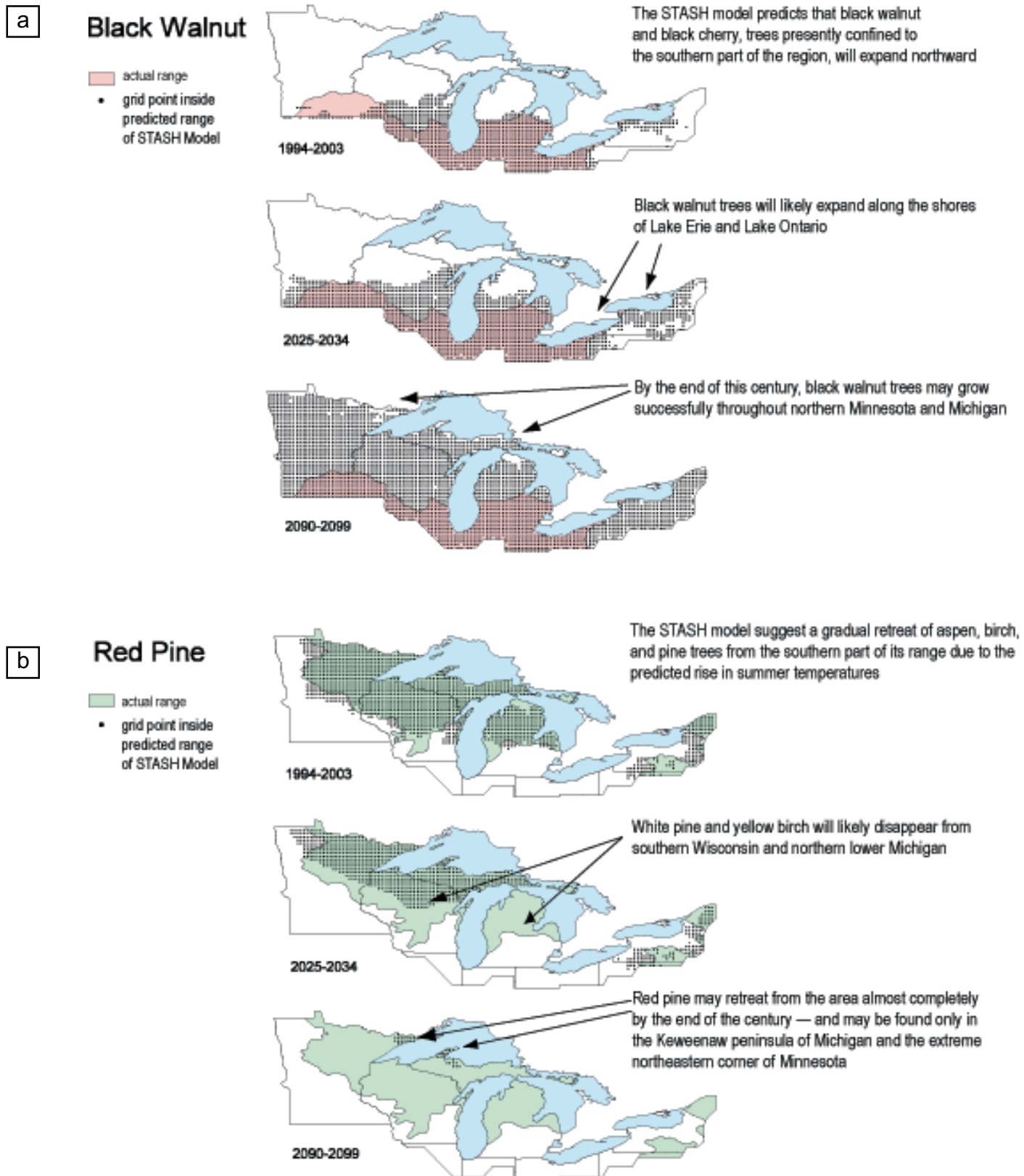


Figure 6.4: Actual (Little, 1971) and predicted (STASH plus the highest tolerated temperature of the warmest month) ranges of a) black walnut and b) red pine in the Great Lakes region.

dicted a marked retreat to northeastern Canada for sugar maple, given the dry central continent predicted by the GFDL model, but persistence within the Great Lakes region rather similar to the present prediction using output from the GISS model.

The third category is composed of species that are predicted to retreat gradually from the southern part of their ranges in the Great Lakes region due to the predicted rise in summer temperatures. Some of the most important timber trees are included in this category: quaking aspen, yellow birch, jack pine, red pine, and white pine (Figure 6.5). By 2099, aspen is predicted to grow only in northernmost Minnesota, Wisconsin, and Michigan, and in the mountainous region of New York and Pennsylvania. White pine and yellow birch will likely disappear from the south, but at the end of the 21st century they should still be able to grow in Northern Minnesota and the Upper Peninsula of Michigan. Jack pine and red pine are predicted to retreat from the area almost completely. By 2099 the only suitable habitats within the region will be on the Keweenaw peninsula of Michigan and the extreme northeastern corner of Minnesota. Similar patterns are shown by Prasad and Iverson [6-11] for red pine, white pine, aspen and yellow birch, although the five climate models differ in their predictions of how dramatic the retreats will be. Current predictions for yellow birch show a greater retreat from the region than the early predictions by Davis and Zabinski using the GISS model [6-9].

The fourth category includes only beech. The results from the current study suggest that this tree may expand westward. Davis and Zabinski [6-9] showed beech retreating from its western limit and moving northward under the GISS climate scenario; under the GFDL climate scenario there was a much larger range movement in the same general direction. Prasad and Iverson [6-11] predicted complete elimination of beech from the Great Lakes region. All of the above studies have had difficulty specifying the climate parameters that correspond to the present range of beech. This may explain why results differ so widely, and adds considerable uncertainty to future predictions.

Decadal maps (not shown) indicate a “flickering” of range limits of several species in lower Michigan from one decade to the next. Soil moisture in this region hovers around the limits for white pine, red pine, yellow birch, sugar maple, black cherry, red oak, and beech throughout the 21st century. Favorable habitat is predicted in lower Michigan for sugar maple, black cherry, red oak, and beech at the end of the century, but these species are predicted to be able to grow there in some decades and not in others. White pine, red pine, and yellow birch display this flickering pattern before disappearing altogether due to warm summer temperatures. “Flickering” trees may survive in favorable habitats (perhaps fine-grained soils) and be exposed to moisture stress in less suitable habitats. Stressed trees will doubtless be very susceptible to insect attack, disease, and disturbance.

Comparing Effects of Landuse and Climate Change on Vegetation

With recent exceptions [6-15], almost none of the work on evaluating the impacts of climate change on natural ecosystems considers the effects of land management. For example, although the region contains significant forest area, about 40% of the land is used for agriculture and much of the forest area is used in some way for forestry. The assessment models are unlikely to capture either the full range of possibilities available in a managed landscape for responding to or mitigating climate change impacts, or the interactions between management and succession. Furthermore, land management activities can modify such ecologically important variables as seed sources and the introduction of exotic species (e.g., gypsy moth and asian longhorn beetle).

The distribution of vegetation communities is summarized in the current assessment [6-16], but in a manner that accounts for the current landuse patterns. This work represents an important attempt to consider land management in the evaluation of potential impacts of climate change on terrestrial ecosystems. Two types of results are presented: (1) changes in the prevalence of seven natural vegetation types as a result of

contemporary landuse and under climate change scenarios; and (2) changes in net primary productivity (NPP) in these ecosystems as a result of landuse and climate change.

Changing Vegetation

The influences of contemporary landuses and various climate change scenarios on the composition of the region in terms of vegetation types are shown in Figure 6.5. The long and short grass prairies provide important habitat for a variety of species that have been driven out by conversion to agricultural uses. According to this analysis, about only 1% grassland remains in a natural state due to the agricultural activities on those lands. The areas of temperate deciduous forest and temperate deciduous savanna are similarly affected by the presence of agriculture (only 24% and 31% remain natural, respectively). The vegetation type least affected by current landuse is boreal coniferous forest, which is also the rarest in the region.

Static type vegetation models predict the disappearance of the boreal forest from the region under doubled atomospheric CO₂

concentrations. Figure 6.5 shows a consistent and substantial reduction in the amount of area covered by both the temperate continental coniferous forest and cool temperate mixed forest types. This suggests that the northern hardwood forests that sustain the regions with the forest products industry, are projected to undergo substantial conversion to temperate deciduous forest and temperate deciduous savannas. The results for the grasslands were mixed, depending on the moisture projections in the climate scenarios and the assumptions about water use in vegetation models. The fact is, however, that very little natural grassland remains and the fate of the grasslands has more to do with agricultural policies and economic conditions than with climate.

Given the substantial projected expansion of the temperate deciduous forests and savannas (oak and hickory are dominant) it is important to consider two limiting factors. First, between two-thirds and three-quarters of these two communities are under active human management for agriculture and/or development. This may affect the availability of seed for sources and, therefore, delay the northward migration of the species

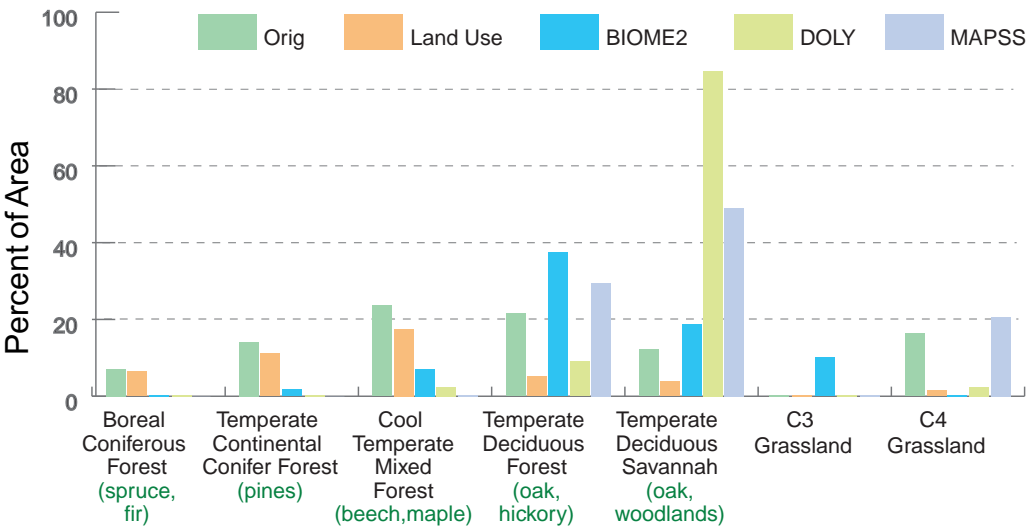


Figure 6.5: The influence of contemporary land use and climate change on the vegetation in the Great Lakes region. The first bar in each group represents the land cover distribution that would exist currently in the absence of any land use. The second bar represents the composition of the region accounting for "non-natural" land uses. The last three bars represent the estimated compositions of the region using three different vegetation models under the climate scenarios (not accounting for land use).

northward. This delay may contribute to the “dieback phenomenon” as communities make the transition from one type to another. Second, the northern forests are strongly influenced not only by climate, but also by the soils present, with conifers tending to dominate on the sandy soils. The soils to the north of the region, especially in Michigan, tend to be very sandy and, therefore, droughty. Although the vegetation models considered this influence, the scale of the variation in soil effects is much finer than can be represented in the models. Therefore, soil effects contribute to uncertainties in the projections.

Changing Natural Productivity

The current assessment results suggest two general trends in changing net primary productivity (NPP). NPP is simply the amount of living plant tissue gained by growth, less the amount lost through death, relocation, per unit area, per unit interval of time — it is also a key indicator of ecosystem degradation or improvement. First, the modification of landscapes through landuse has a much greater impact on the level of net primary productivity than will the projected levels of climate change. Estimates from biogeochemistry models under changed climate scenarios project changes in productivity between a decrease of 10% and an increase of about 50%. However, active management takes over half the land out of natural production and causes a current decrease in net primary productivity of about 50%. The changes in natural net primary productivity as a result of climate change are going to be restricted to those areas that are not actively managed.

The second trend is a likely increase in productivity to levels slightly above present levels. The best guess value, is an increase of about 20%. This increase comes about from longer growing seasons and increased water use efficiency. Growth chamber experiments with young aspen in Northern Michigan show between 15 and 30% increase in productivity due to elevated CO₂ levels alone, depending on site conditions (Note: This estimate does not account for any changes in disturbance regimes, increase in nitrogen deposition, any change in cloudiness, or changes in landuse). However, rapid rates of landuse change

could overwhelm changes due to climate change. Given the vegetation scenarios described above, the forests will need to change their mix of species before attaining this increased productivity. The amount of time it will take for this to occur is still debatable, although prior studies suggest a time frame on the order of 200 years [6-5]. So, if mortality substantially within the time frame of this assessment (an uncertain possibility), then decreases in productivity are more likely.

Evaluating Economic Impacts of Climate Change on the Forestry Industry

Despite the importance of landuse on net primary productivity, the impact that climate change (alone) would have on the forest industry in the Great Lakes region could be substantial. As indicated in the above section, important timber species (aspen, jack pine, red pine, white pine, etc.) will be lost from our region. The socioeconomic implications of the type of forest land transition shown in Figure 6.4 are significant. From a purely economic point of view, perhaps the greatest loss would be to the strong virgin pulping/wood fiber industry that now exists in the Great Lakes region. A strong shift toward oak-hickory would completely eliminate the soft wood pulp industry and create difficulty for board mills, OSB plants, and other forest product industries that rely primarily on softwood feedstocks. This would effectively require closing many mills in Michigan and Wisconsin unless significant technological advances were made that allow the greater consumption of hardwood fiber for use in these threatened industries.

The effect of this transition on consumer wood products, manufactured wood products, and other wood-related specialty industries is less clear. If these industries are flexible and capable of switching from softwoods to hardwoods as raw materials, then they will (continue to) do well. From a more social perspective, the effect will also be significant. Clear negative impacts to the quality of life and tourism dollars may occur with the disappearance of aspen and many of the characteristic conifers, such as jack, red and white pine that characterize today's

landscape of the northern Great Lakes region. Logging has already reduced the abundance of red and white pine, but they remain as characteristic species in Itasca State Park, the Boundary Waters Canoe Area, and, in lesser abundance, in the Porcupine Mountains and other parks that attract visitors to the region.

Coping Strategies

There seem to be few options for halting this significant change in the regional forest ecosystem. Therefore the most effective approach for coping with this change is anticipating its effects and trying to mitigate them through steps that prepare citizens and industries for the changes.

The following ideas for coping strategies came out of the Upper Great Lakes Region Workshop. First, a reasonable response strategy within the forestry and land management communities in the Upper Midwest is to monitor the health of the forests in response to their changing environment from climate change, changing air quality, pest and disease outbreaks, and forest fragmentation due to development. Fire and pest management strategies may need to be reconsidered from a changing climate perspective (Figure 6.6). The incorporation of integrated pest management and prescribed burning may reduce the indirect effects of these disturbances with a changing climate.

Landuse conflicts may occur as a more dispersed settlement pattern continues to develop and as competition among vari-



Figure 6.6: Asian longhorn beetle infestation in Chicago: before, during, and after cleanup. The only control available now is to identify which trees are infested, cut them down, and chip them into tiny pieces. Such an approach can turn a tranquil neighborhood with tree-lined streets into a barren landscape. Source: Agricultural Research Library Photo Gallery; Photo by Michael T. Smith.

ous landuses change with changing climate. Policies, such as landuse planning and/or “sprawl” taxes, might be used to minimize landuse conflicts. However, it must be understood that current strategies are failing. For example, attempts to minimize sprawl (e.g., Subdivision Control Act, zoning) in the past have not met with great success. The political costs of abridging land ownership rights in the region could be high.

Where possible, some attempt should be made to facilitate the migrations of plant species with the shifting of ecological zones. The establishment of migration corridors was suggested at the Upper Great Lakes Region Workshop as a possible mechanism to reduce the effects of fragmentation. However, maintaining a corridor may not be successful if flowering is limited due to climatic changes. Following harvest, tree species that are better suited to a changed climate might be planted to encourage adaptation of the ecosystem. Species and genetic diversity should also be encouraged to improve natural adaptive capacity.

Finally, and most importantly, public and private education programs regarding the potential risks and consequences associated with rapid changes in climate should be in place. For example, the potential for increasing fire danger associated with warmer and drier conditions should be communicated to homeowners in high fire-risk ecosystems. The increased potential for flooding associated with increases in the frequency of heavy precipitation events should be communicated to flood plain landowners. The pulp and wood product industries should incorporate the change in forest patterns into capitalization plans as soon as possible (in these capital intensive industries decisions are frequently made with 20-30 year time horizons). Local communities should begin a program of planting tree species on their streets and parks that will thrive in the changed climate in order to avoid effects like those caused during the Dutch Elm disease epidemic in the 1960s and 1970s. While none of these steps is likely to replace lost revenues or other industrial activity, it is possible that the devastating effects that occur when change encounters an unprepared industry could be mostly prevented.

Information & Research Needs

Although the Upper Great Lakes Region Workshop identified several information needs, two are particularly relevant to the assessment presented here.

One important need is to use climate output from atmospheric models with higher resolution. The range-limit results for tree species were obtained in the present study using output from a coarse resolution GCM - that does not include the effects of the Great Lakes. Some of the finer-scale aspects of the results in Figures 6.4 might therefore differ if output from a higher-resolution regional climate model, that accounted for lake-effect cloudiness, precipitation, temperature moderation, and (severe) storm development, for example, were used. A better understanding of the relationships between bioclimatic variables and range limits should also lead to better predictions of the impacts of climate change on tree species.

Another important information need is the one to couple models of ecosystem productivity with models of landuse change to study change under altered climate. The magnitude of the landscape alterations in the region suggest that land management will continue to be important, perhaps more so, in determining the productivity of the landscape.

Dynamic (transient) models of ecosystems, like the gap models used by Solomon [6-6] need to be combined with spatially distributed models of landscape function in a manner similar to He et al. [6-15]. Spatially and temporally explicit models allow for the incorporation of a number of effects not already considered in these assessments. These include the response of disturbance regimes to climate change, the effect of seed dispersal on the rate of species establishment, and the analysis of patchy landscapes (i.e. landscapes that are not completely natural).



FOCUS

EFFECTS OF CLIMATE CHANGE ON BIRD DISTRIBUTIONS AND MIGRATION PATTERNS

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The Great Lakes region supports more bird species than anywhere else in the conterminous US except for northern New England [F6-1]. The region is the only place in the world where the endangered Kirtland's Warbler breeds. This species nests in young (5-23 years old) jack pine stands with specific vegetation characteristics found mainly in areas of northern lower Michigan. The Great Lakes region is important for many migrating birds as well. Hawk Ridge, located just outside Duluth, Minnesota, and areas along the Detroit River are corridors for the Broad-Winged Hawk migration. The Upper Mississippi/Trempeleau National Wildlife Refuges, located along the Mississippi River between Minnesota and Wisconsin and continuing farther south into Illinois and Iowa, host more than 100,000 Canvasbacks (>20% of the world's population) and more than 200,000 ducks of other species during their annual southbound fall migration. Bald Eagles also use this refuge, with more than 600 being found there in the winter [F6-2]. To date, more than 40 globally important sites (e.g., sites that regularly provide habitat for 1% or more of the world's population of a bird species) have been identified in the Great Lakes region including nine in Minnesota, five in Wisconsin, and eight in Michigan [F6-3].

Economic and Ecological Impacts

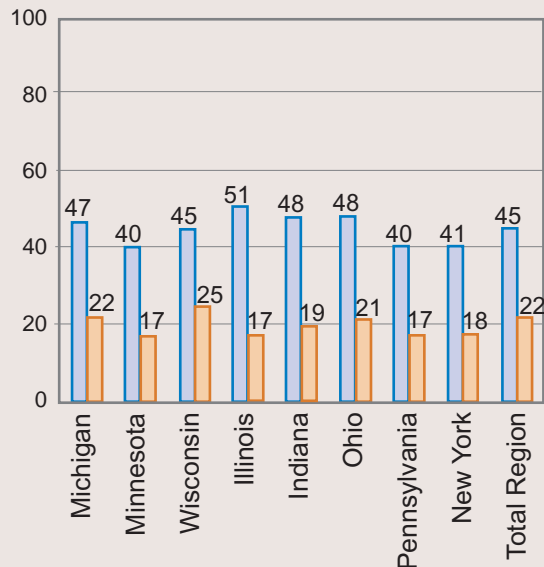
The diversity and abundance of birds have an overall positive economic impact in region. Nearly \$3.5 billion was spent on wildlife-watching activities in 1996 in the Upper Great Lakes region (Minnesota, Wisconsin, Michigan) alone [F6-4]. The majority of this amount was spent on watching or feeding birds. An earlier survey found that “non-consumptive” (e.g., non-hunting) bird use generated \$590 million in retail sales in Michigan, Minnesota and Wisconsin, and supported more than 18,000 jobs [F6-5]. Additionally, more than \$3.8 billion was spent on hunting in Michigan, Minnesota and Wisconsin in 1996 although this figure includes expenditures not only for migratory bird hunting (mostly waterfowl) but also expenditures for big-game (e.g., deer and moose) and small-game hunting. Birds also provide many important ecological services to ecosystems in the region. For example, Blue Jays are a major disperser of oak seeds; several species of warblers are largely responsible for holding down numbers of eastern spruce budworm larvae, eating up to 98% of the non-outbreak larvae; and birds in general consume up to 98% of the overwintering codling moth larvae in orchards. Also, while birds are not the principal vertebrate predator of gypsy moths (the white-footed deer mouse is), they do play a role in holding down numbers of this pest. Birds also play a role in many Native American communities. Birds, or bird parts, are used in some religious ceremonies and also form a component of the subsistence lifestyles in these communities.

While people certainly care about birds, it is difficult to estimate how changes in bird distributions might affect the economics of consumptive or non-consumptive bird use. Shifts in regional spending are likely as some birdwatching and hunting sites become less favorable and different sites become more favorable. Although many birdwatchers and hunters might simply adjust to the reduction in species richness in their areas, they will experience the loss of well-being that accompanies a reduction in their preferred activities. Shifts in the distributions and abundances of wildlife are likely to have a greater impact on Native Americans in that their communities are often geographically restricted and unable to follow the wildlife in response to the changing climate.

Bird Distributions and Climate Change

Recent studies (Figure F6-1) have suggested that bird distributions may change quickly in response to climate change – the average latitude of occurrence of 43% of the warblers has shifted north in the last 20 years, by an average of more than 44 miles (70 km) [F6-6]. In contrast, only three species (6%) were found significantly farther south and those represented overall expansions of the species’ ranges. In most of the remaining species, the range showed a northward trend but it was not enough to be statistically significant. While it is impossible at this time to attribute this shift to climate change alone it does indicate that at least some of the warblers might be susceptible to even slight changes in climate. Early studies [F6-7, F6-8] of potential climate change impacts on the habitat of this species projected a potential rapid loss of this habitat type [F6-9]. This was of particular concern because, although jack pines have a broad distribution, Kirtland’s Warblers are not known to breed outside of this very small area. In recent years, Kirtland’s Warblers have been found breeding on the Upper Peninsula of Michigan with isolated sightings in Wisconsin and Ontario. While this is encouraging, populations in this area will need to increase in order to offset the risk of habitat loss in the core of its

Perching Birds



Warblers

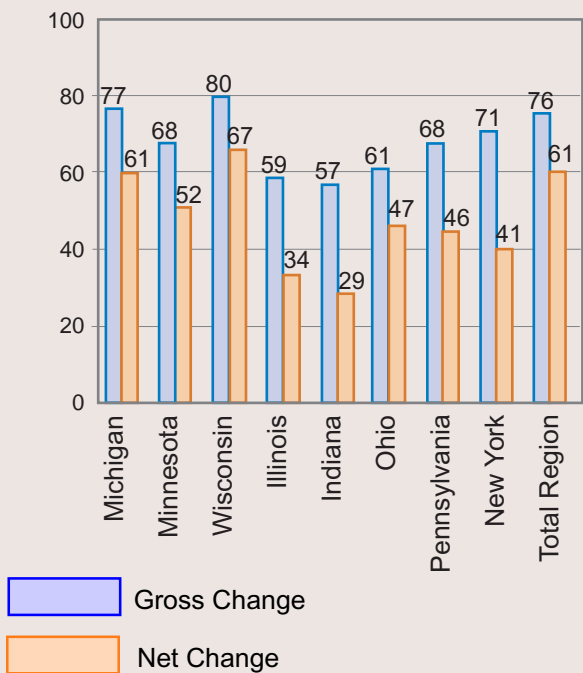


Figure F6.1: Reductions (%) in the number of perching bird species and warbler species from the equilibrium Canadian Climate General Circulation model. The gross change represents the overall loss currently found in the area. The net change represents the loss of species currently found in the area offset by the species moving into the area from outside of the region.

range. The ideal habitat for this species is one in which frequent fires occur, to maintain the proper age-class and structural components of the jack pine forests. Some equilibrium climate change models project the possibility of an increasing forest fire frequency, which suggests an increase in the amount of habitat available for this species. Even if the amount of available habitat increases north of this species' current range (e.g., Michigan's Upper Peninsula and Ontario) the species will still need to colonize these new areas and have sufficient time to establish viable populations before its current habitat becomes unsuitable. While many more species will likely leave the region, some of these losses will be offset by other species moving into the region. However, more recent studies suggest that climate change will likely lead to a net reduction in the number of bird species in the Great Lakes region.

Bird Migration in the Upper Peninsula

Of the 47 species of birds that have been noted to migrate through the region, four have now become resident on the Upper Peninsula. These are species that formerly migrated some distance south in the fall and returned in the spring. No significant change was found for 27 of the species and one species is actually arriving later. The remaining 20 species were found to be arriving an average of 19 days earlier in 1994 than in 1965. These species have many different migratory strategies, some are short-distance migrants and some migrate from Central and South America. While there is no direct link between the early arrival of these species and climate change, the earlier arrival is associated with earlier pond thaw dates in the area. This suggests that temperature increases since 1965 may be associated with these species earlier arrival

dates. The timing of migration, and the timing of breeding are thought to be tied largely to the availability of resources, predominantly food. Many bird species time their breeding such that there is a flush of insect larvae available for them to feed their young. If early spring migration leads to early breeding, then there could be a “decoupling” of birds from their dominant food resource. Unless the insects hatched at an equivalently earlier time, there might not be as much food available for the birds to feed their young. Similarly, this could lead to a breakdown of control mechanisms between predator (birds) and prey (insect larvae) potentially leading to more damaging insect outbreaks of some species.

Waterfowl and Climate Change

Climate change may also impact the migration of other (waterfowl) species through the region [F6-10]. Declines in duck numbers from 39% to 19% are projected to occur by the 2030s. These declines will likely have an impact on waterfowl hunting opportunities and a subsequent loss of revenue associated with waterfowl hunting. These declines from loss of breeding habitat may be exacerbated by loss of migratory habitat, which still needs to be considered more thoroughly. Many of the diving duck species feed on submerged aquatic vegetation or invertebrates (including zebra mussels) to store fat in order to continue their migration. The availability of these foods, in turn, is often tied to water depth and mixing characteristics. Changes in lake water levels or temperatures could have an impact on these species. Many of the ducks also rely on the wetland marshes for food and shelter during migration. Rising lake levels could flood out potential marsh habitat while declining lake levels could dry out the marshes – making them unavailable for waterfowl. Finally, any increases in dredging necessitated by falling lake levels could introduce contaminants into the food chain that could be harmful to waterfowl.



7. AGRICULTURE

study conducted by

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Agriculture in the Great Lakes region follows a south to north gradient. Intensive rowcrop monoculture exists in southern sections and gradually gives way to forests and other natural vegetation across the north (Figure 7.1). Southern sections of the region form the northern boundary of the US Corn Belt region, with corn, soybeans, hogs, and cattle as major commodities. Dairy and associated alfalfa production are common in the driftless area of southeastern Minnesota and southwestern Wisconsin and scattered across central and northern sections of the region. Vegetable production is centered in the Central Sands area of central Wisconsin, across lower Michigan, and in the Red River Valley of Minnesota, which also forms the eastern boundary of the Great Plains small grain production area. Fruit and ornamental crops are grown intensively along the eastern shore of Lake Michigan.

Agriculture ranks among the most important economic activities of the Great Lakes region, accounting for more than \$15 billion in annual cash receipts [7-1]. Livestock, including dairy, is the number one agricultural commodity group, comprising over half of the total. Dairy production alone produces almost \$5 billion in receipts. Other major commodity groups

include: grains/oilseeds, vegetables, ornamentals, and fruit. Crop diversity is an important characteristic of agriculture in the region due at least partially to the moderating influence of the Great Lakes on regional climate [7-2]. Over 120 commodities are grown or raised commercially in the region [7-1].

Current Stresses

The major stresses on agriculture in the Upper Great Lakes region can generally be categorized as economic, social, environmental, and regulatory (Figure 7.2). The amount of water and the frequency of its availability are primary climatological constraints for the production of most annual crops [7-3]. Growing season precipitation provides the bulk of the moisture used by crops during the season, with the remainder provided by soil moisture storage accumulated during the off-season. Several factors will affect water management and water withdrawal for agricultural use in the future: the availability of groundwater and surface water; supplemental irrigation requirements; the real cost of energy for pumping; uncertainty regarding water application and crop yield; technical developments for management of irrigation delivery systems; and adverse environmental impacts from irrigation. The issue of adverse environ-

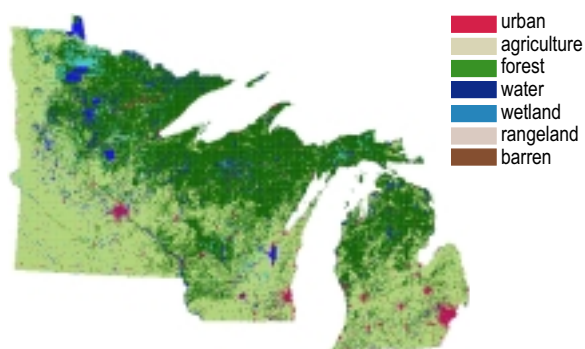


Figure 7.1: US Geological Land Use Data (LUDA), ca. 1980.

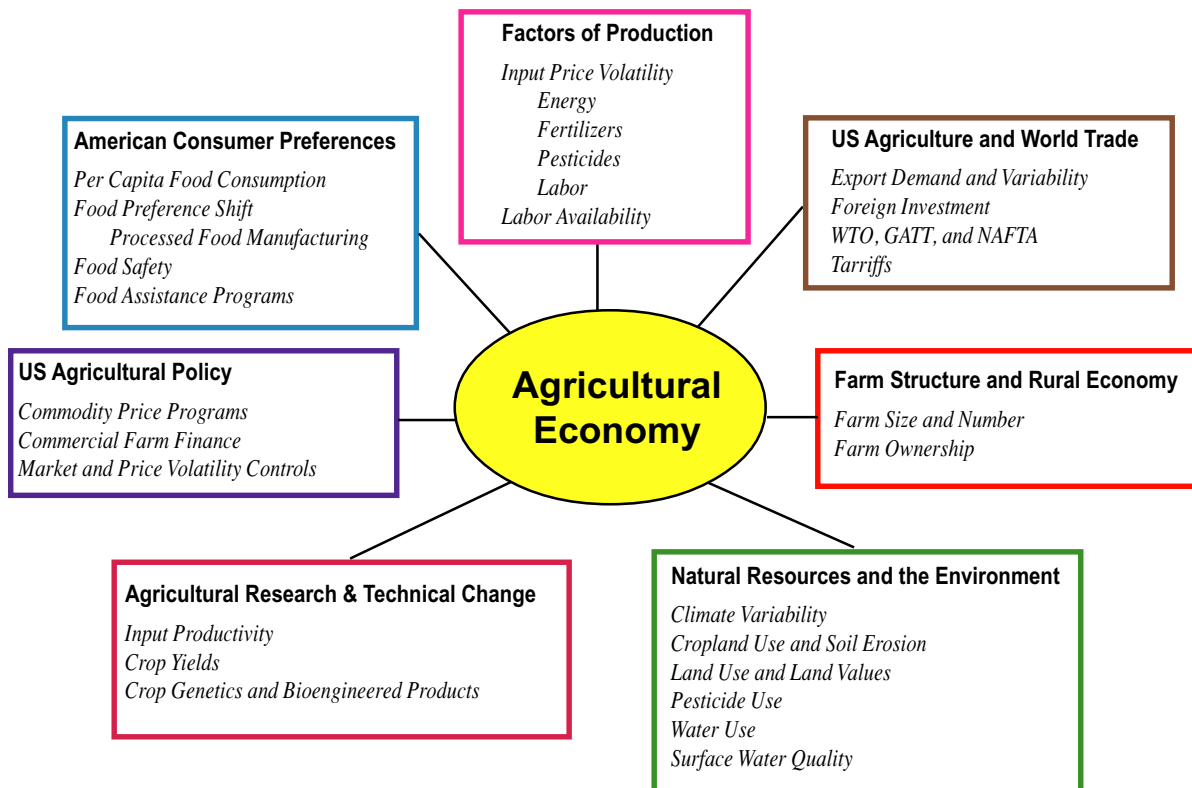


Figure 7.2: Factors that influence agricultural production.

mental impacts, in the form of non-point source pollution, may become more widespread with more intensive irrigated crop production on light soils and the predicted changes in water levels in the Great Lakes.

Another major stress in the Great Lakes region is the current low commodity price for most major field crops and the difficulty of gaining access to export markets. One-third of US commodities are marketed through foreign trade, but farmers' access to international markets is blocked through foreign market barriers, regulations and sanctions. These barriers have continually hurt US farmers, who typically produce about a third more than Americans can consume. Given that 95% of the world's consumers are outside of the United States, "the answer is not in cutting United States production, but rather in finding a home for these commodities," said Bob Boehm, Michigan Farm Bureau commodity and marketing department manager. "We can compete in the global marketplace, but we need access to those markets."

Deterioration in overall financial performance has also occurred in the Upper Great Lakes region. The region exhibited a significant decline in the percentage of farm businesses classified in a favorable financial position and an increase in the share considered vulnerable. The Great Lakes region was one of the few areas of the country where the average farm business debt/asset ratio increased in 1997. Its average of 0.24 was the highest among the different production regions. At the end of 1997, the Great Lakes region had the highest concentration of highly leveraged farms where at least one out of five farm businesses had a debt/asset ratio above 0.40 and lower income and increased debt pushed debt repayment capacity utilization to dangerously high levels [7-4].

Given significant land use changes occurring across the region, farmers are facing increasing pressure from urban encroachment and the loss of prime or productive agricultural land to urbanization [7-5]. The future rate of change of this loss is dependent on growth of population, especially around urban areas, and the vitality of regional economies. In the last 15 years, Michigan and

Wisconsin have both lost over 1.4 million acres of cropland and Minnesota has lost over 0.7 million acres, according to the 1997 Census of Agriculture [7-6].

Environmental factors like climate and its inherent variability; long-term degradation of soil resources; geographical concentration of livestock production and the associated management of large amounts of livestock waste, and the contamination of surface waters and groundwater by agricultural chemicals may also create direct stress on regional agriculture [7-7].

Finally, one category of stresses that integrates many of the above factors is governmental regulation, which may drastically change standards or alter the economics of the production system. One current example is the gradual implementation of the 1996 Food Quality Protection Act, which may ultimately result in the loss of many pesticides used commercially in agriculture (especially in fruit and vegetable production) and for which few, if any, substitutes now exist [7-8].

The potential impacts of climate change on regional agriculture will depend greatly on the magnitude, timing, and the variability associated with the change. Variability is generally considered to be the most difficult aspect with which to cope and adapt [7-9]. Most of the recent research on climate change in the Great Lakes region has suggested a warmer and wetter climate in the future [7-10], with relatively more warming occurring in the winter and spring than in other seasons [7-11]. Agriculturally, this would most likely lead to a longer growing season and greater potential productivity, but also to greater potential rates of evapotranspiration. An additional critical factor in determining potential productivity is CO₂ enrichment, which has been associated with increases in total plant dry matter accumulation and improved crop water use efficiency through decreases in transpiration rates. While some research studies have shown that yield-increases from higher atmospheric CO₂ levels may actually decrease when other resources are limiting and that the enrichment effect may decrease over time for some plant species, most scientific literature suggests

that there will be significant long term benefits to agriculture as atmospheric CO₂ levels increase in the future [7-12].

There may be potential changes in the productivity of arable land for specific crops in sub regions, especially where specialty crops will be sensitive to increases in CO₂ enrichment, temperature or rainfall during critical growth periods. This analysis indicated that these changes might be especially true for crop simulations at southern and western study locations with the relatively warmer and drier CGCM1 model. Potential productivity may also be affected by changes in the rate of vegetative development in a season prior to the last spring frost and in the frequency of subfreezing temperatures after critical growth stages for specialty crops such as cherries. (Focus – *Climate Change and Fruit Production: An Exercise in Downscaling*)

Other economic changes may occur in the commodity prices for field crops driven by worldwide changes in production and demand. This may affect the profitability of farm operations. There is likely to be an increasing dependence upon agriculture's use of rail and truck for moving agricultural commodities to market due to decreased capacity of shipping on the Great Lakes (Focus – *Climate Change and Shipping/Boating*). Finally, the impact of regulations may dictate changes in farming practices, including the types and amounts of fuel and fertilizers used to produce crops that can affect the cost structure of farm operations.

Current Assessment

There have been few past studies concerning climate change and agriculture in the Great Lakes region. The major objective of this study was to determine the impact of weather and climate on three crops commonly grown in the region: alfalfa, a forage used extensively for dairy production; maize, a coarse grain; and soybean, an oilseed. Daily weather data were obtained from the daily VEMAP series based on the two GCMs (HadCM2 and CGCM1). Additionally, simulation models based on the physiological processes that govern growth and devel-

opment of the crops were used: DAFOSYM, CERES-Maize, and SOYGRO, for alfalfa, maize, and soybean crops, respectively [7-13, 7-14, and 7-15]. The simulation models have been successfully used in a wide number of past studies and applications [7-16, 7-17, and 7-18].

Model Historical Trends

Several trends were identified using the historical climatological data and the model simulations. Increases in growing season precipitation were found at 10 or more of the 13 locations (Figure 7.3) for all three crops. Increases in simulated soil moisture available to the plant at mid-season, a key variable in determining ultimate yield potential, were also found for maize (11 of 13 locations with increases) and soybean (12 of 13 locations with increases). In contrast, simulated potential evapotranspiration, the potential loss of water due to soil evaporation and plant transpiration, was found to decrease at 11, 10, and 9 of the 13 locations for alfalfa, maize, and soybean crops, respectively. As a result of the trends towards wetter, less stressful conditions, increases in both maize (positive trends at 11 out of 13 locations) and soybean (positive trends at all 13 locations) yields occurred across much of the region. Alfalfa yield trends were mixed, with decreases at 8 locations and increases at 5 locations. Overall, greatest increases in simulated yields for all crops over time were found at western and northern study locations.

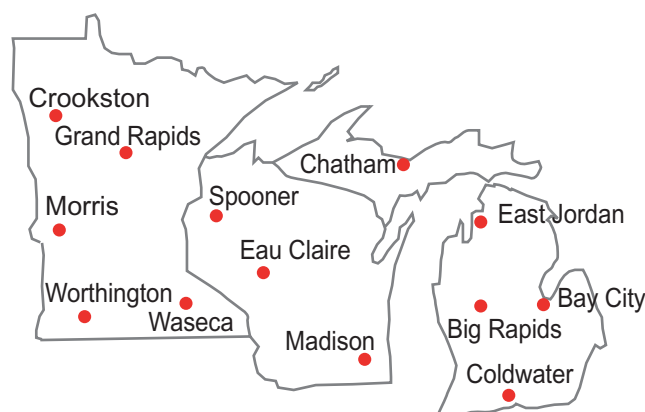


Figure 7.3: The 13 study locations.

Model Projected Future Trends

Both model simulations suggest an overall warmer and wetter climate by the year 2099 across the region. The CGCM1 model is the warmer of the two models, with a 7.2°F (4°C) or greater increase in mean annual temperatures at the study locations by 2099 versus a 4.5°F (2.5°C) increase for the HadCM2 model. Average annual precipitation totals across the region generally increase from approximately 31.5 inches (80 cm) at 2000 to 39.4 inches (100 cm) at 2099 for both GCMs. However, the rate of precipitation increase for the HadCM2 GCM is much more consistent over the 100 year period than for the CGCM1 Model, in which much of the overall 100-year increase occurs during the last 20 years of the period.

A comparison of historical and potential future simulated yields for the three crops averaged from 2000-2099 and across all 13 study locations for both GCM and CO₂ enrichment scenarios is shown in Figure 7.4. In general, the warmer and wetter climate suggested by both GCMs leads to increases in average simulated non-CO₂ enriched crop yields relative to historical yields, ranging from 6% for alfalfa in both GCMs to 26% for maize in

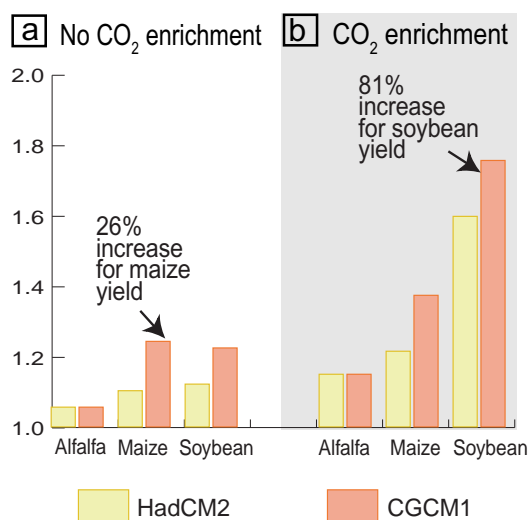


Figure 7.4: Ratios of GCM-projected future (e.g. 2000-2099) crop yields to historical observed crop yields averaged over 13 stations. Note: CO₂ refers to the inclusion of plant impacts resulting from enhanced CO₂ concentrations in the simulations in addition to climate change impacts.

the CGCM1 model. When the impacts of CO₂ enrichment are also considered, the yield differential relative to the historical period increases to a range of 16% for alfalfa to 81% for soybean in the CGCM1 model. Largest percentage increases in yield across the 2000-2099 study period were at northern locations. The ratios of the future scenarios with and without CO₂ enrichment suggest that the majority of yield increases during this period are due to CO₂ enrichment.

The ratios given in Figure 7.4 represent averages over the entire 100-year future period. Most of the simulated yield series actually exhibited consistent increases through the period, especially with the HadCM2 model output. Other yield series tended to decrease across the period, or increase during the initial decades of the period, followed by decreases later in the period. The latter pattern was especially true for crop simulations at southern and western study locations with the CGCM1 model. Simulated historical crop yields across the region also tended to increase with time during the past 50-60 years, due at least partially to concurrent increases in growing season precipitation and decreases in potential evapotranspiration.

The model simulation results suggest that the warmer and wetter climate for the Great Lakes region may lead to a northward shift of some current crop production areas [7-19]. Even with less suitable soils agronomically, the model simulations suggest that yield potential may improve at three of the northernmost study locations currently outside major agricultural production areas: Chatham, Michigan; East Jordan, Michigan; and Grand Rapids, Minnesota (Figure 7.5). The average yields for maize and soybean increase dramatically by the 2090-2099 decade relative to historical yields, ranging from 276% (263%) for soybean to 343% (373%) for maize in the Hadley (Canadian) model. The increases for alfalfa were smaller at 29% (26%) in the Hadley (Canadian) model.

The model simulation results from the two GCMs differ somewhat, but suggest that crop yields in the future may be substantially greater than those observed during the past century due

to the effects of CO₂ enrichment and because of more favorable growing season weather, especially in northern sections of the region. Some crop yields simulated with the relatively warmer CGCM1 scenario were greater than historical yields through 2050, but tended to decrease with time from 2051-2100, especially at western and southern study locations. The simulations also suggest that the fraction of total water used by crops during the growing season that is supplied by long term soil moisture storage (and not by recent precipitation) will decrease, making water shortages and moisture stress less likely than in the past. Finally, a number of projected future yield series exhibit decreasing interannual variability with time, which was associated with decreases of growing season temperature and precipitation variability.

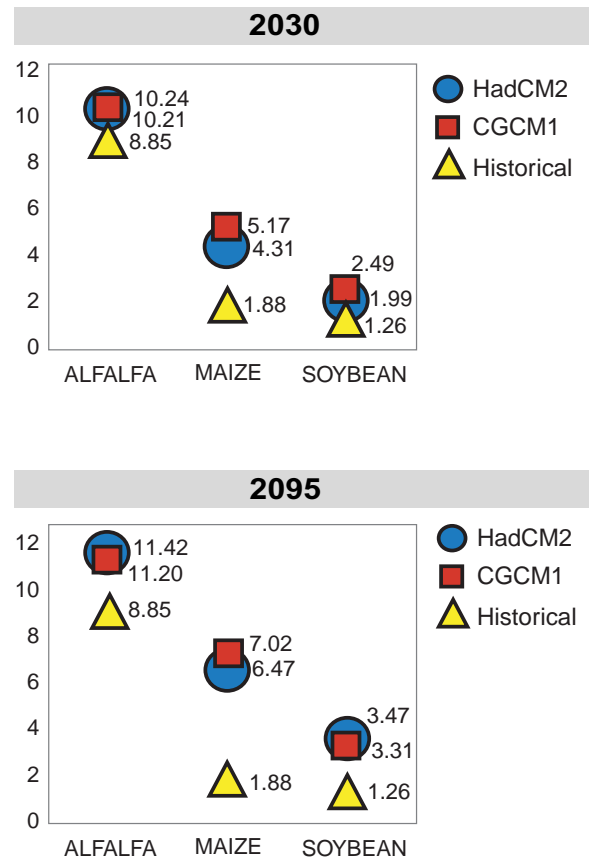


Figure 7.5: Average model simulated crop yields (ton/acre for alfalfa, bu/acre for maize and soybean) with CO₂ enrichment at three northern-most locations for 2025-2034 and 2090-2099 time periods. Historical (1896-1996) yields shown for comparison.

Economic Considerations

Water is used for agricultural irrigation on a small percentage of the harvested cropland in the study region. (Table 7.1). Irrigation water is applied as a supplemental production input to natural rainfall, especially during short periods of drought. Irrigation is applied because the rainfall is not adequate or reliable during the critical growth stage, the soil may offer a low soil moisture holding capacity that may increase the need to irrigate during critical stages, or the crops are water intensive and are subject to soil moisture stress [7-20].

Table 7.1: Land under irrigated agriculture in the upper Great Lakes (US Census of Agriculture, 1997).

State	Total Cropland (acres)	Harvested Cropland (acres)	Irrigated Cropland (acres)
Michigan	7,891,802	6,724,480	393,485
Minnesota	21,491,743	18,968,607	380,394
Wisconsin	10,353,300	8,625,011	341,813
TOTAL	39,736,845	34,318,098	1,115,692

The estimation of the quantities of water required for irrigation, however, is an integral component of the framework to determine the total water withdrawal or the consumptive use within the study region, especially within basins that may experience water shortages due to climate changes and have more intensive agricultural development. There is the potential for changes in irrigation demand in certain localized, but limited areas, that already have a higher percentage of farms utilizing irrigation due to the increase in temperature. A small percentage decrease in the amount of water used in agriculture could greatly reduce the possibilities for water conflicts and enhance the possibilities for economic growth within the region. The comparative stability of surface water use for irrigated agriculture in the face of increasing water scarcity reflects the insulation of water costs to surface irrigators from market considerations and energy costs [7-21].

Agriculture use generally exhibits a relatively low marginal value for water use. The incentives for farmers to utilize water

more efficiently without incurring financial losses and their ability to substitute other production inputs (labor, energy, fertilizer, and pesticides) are the keys to the future viability of irrigated agriculture, especially in basins or sub-basins that exhibit water scarcity. The efficient and productive use of factors of production on the farm, the policies that affect the technology or preferences underlying the demand for supplemental water, the associated costs, and the resulting profit in relation to climate change variables are major issues to be investigated in the Great Lakes.

Coping Strategies

If the magnitude of regional climatic changes in the future reaches values suggested by GCMs, farmers will be forced to adapt to the changes or become uncompetitive and unprofitable. Improvements in technology, the CO₂ fertilization effect, and the use of adaptive farm management strategies should help farmers mitigate any negative effects of climate change for the majority of farm operations in the Great Lakes region. Adaptive farm management strategies include: changes in crop selection or variety (using crop varieties that are currently used in more southern regions) changes in the timing of planting and harvesting; the development of new varieties of crops that are more adaptable to interannual variations of weather; double cropping; irrigation; and other unforeseen technical improvements.

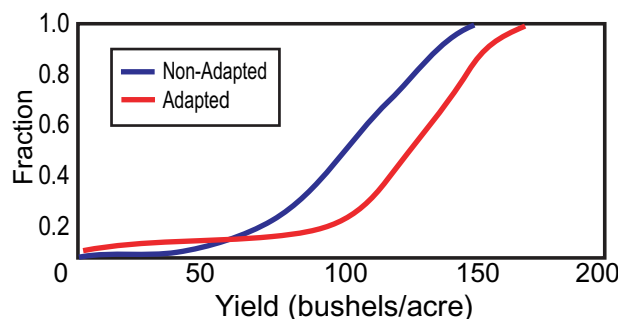


Figure 7.6: Cumulative simulated frequency distribution of adapted vs. non-adapted crop varieties, for Coldwater, Michigan using output from the HadCM2 model for the period 2000-2099. The adapted variety required 18% more growing degree days between planting and maturity than the non-adapted variety and was planted 15 days earlier.

As one simple example of the benefit of adaptive strategy, agronomic data in the CERES-Maize crop model was modified to better suit the warmer future climate suggested by the GCMs at Coldwater, Michigan, a location typical of the northern Corn Belt region (Figure 7.6). In particular, the crop was planted 15 days earlier each season (on or after 1 May, depending on weather and soil conditions) and the total number of growing degree day units required for the crop to advance from planting to maturity, was increased 18%. There were total crop failures in 4 of the 100 years of simulation (due to early freezes in the beginning decades of the future scenarios). The adapted crop exhibited a probability of zero yields for a small portion of the distribution. At a probability of 0.11 or greater, however, the adapted yields exceed non-adapted yields and continue as such for the remainder of the distribution, with magnitude of the differences generally ranging from 14.9-26.1 bu/ac (1.0-1.75 t/ha).

There is evidence based on past performance that agriculture will at least be able to partially adapt to a changing climate and that the costs of such adaptations will be small compared to costs associated with an expansion of or changes to major production areas [7-22, 7-23, 7-24]. Ultimately, however, the ability to adapt will likely depend upon the nature of the climatic change, as increases in variability could make future adaptations difficult [7-25].

Based on projections of a warmer and wetter climate, the future scenarios suggest greater agronomic potential for northern sections of the region, even with less suitable soils. Simple adaptations to a changing climate such as a switch to a longer season variety or earlier planting date will likely result in significant increases in potential crop yield.

Information & Research Needs

The current assessment did not consider the impacts of major limiting factors in agriculture such as inadequate fertility or pressure from weeds, diseases, and insect pests. In addition, the projected future weather scenarios are simplistic synthetically-derived series from the coarse-scale, monthly grid output val-

COPING STRATEGY: DOUBLECROPPING



The unusually mild spring of 1998 in Michigan allowed the winter wheat crop (that was planted in the fall of 1997) to reach maturity and be harvest-

ed at a record early pace in the beginning of July. Faced with low commodity prices, extra soybean seed, and an (albeit risky) opportunity for an increase in seasonal receipts, a grower in southeastern Lower Michigan decided to try and plant a second crop of soybeans following the harvest of the wheat. Due to limited growing season length and water available to the secondary crop (soybean), this type of double-crop system has been commercially successful only in warmer, wetter growing areas hundred of miles to the south of Michigan. Abnormally mild fall temperatures, a delayed first killing freeze of the fall season, and timely late summer rainfall favored the secondary soybean crop and allowed yields to reach 40 bu./acre, which translated into cash receipts of \$200/acre, total production costs less than \$70/acre, and an opportunity for profit that has traditionally never existed in Michigan.

ues of the GCMs and represent the output of only two GCM simulations. Future studies based on more representative regional- or local-scale climate simulations, which include these and other limiting factors as well as resulting economic impacts are needed for future risk assessment and for the development of new technologies necessary for commercial adaptive strategies as climate change occurs.



FOCUS

CLIMATE CHANGE AND FRUIT PRODUCTION: AN EXERCISE IN DOWNSCALING

study conducted by

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Fruit production is a significant commercial endeavor in the Upper Great Lakes region and a primary source of revenue for some local areas. It is extremely vulnerable to damage from temperature extremes, particularly minimum temperature extremes. Hence, most of the fruit-growing areas in the region are located near the shores of the Great Lakes, where the water helps to moderate extremely cold and warm air masses. Deciduous fruit trees normally begin a cold hardening or rest stage in autumn before becoming dormant during the mid-and late winter. As temperatures rise in the late winter and early spring, the trees gradually lose their cold hardiness before becoming actively vegetative. Fruit trees in the Great Lakes region are particularly vulnerable to cold damage during spring bloom when temperatures slightly below freezing may kill flower buds following the loss of cold hardiness. Evaluating the potential for day-to-day temperature extremes along the lakeshores is imperative to understanding the impacts of climate change on fruit production. The principal impacts of projected climate change are more likely to result from changes in the frequency of threshold events and extremes, such as the date of last spring freeze, the length of the growing season, and heat accumulation, than from changes in mean climatic states.

Threshold Events

A climatological threshold event is the exceedence of a variable of interest above or below some predefined level (i.e., “threshold”). Assessing possible future changes is a complex undertaking because relatively small changes in mean temperature may produce large changes in the frequency of threshold events [F7-1], and because observed trends of different temperature threshold parameters at a site or adjacent sites may be uncorrelated. For example, in northern Sweden, the length of the growing season was longer during the cold decade of 1979-1988 than during the much warmer period of 1931-1940 [F7-2]. In the former Soviet Union, there have been no (correlated) changes in the start, end, and duration of the growing season despite the observed warmer conditions during the past 110 years [F7-3]. In Minnesota, mean temperature trends at five stations and the duration of the frost-free period appear to be uncorrelated and in opposition to those for stations in neighboring Wisconsin [F7-4, F7-7]. Only a few observational studies support the anticipated behavior between warming and the occurrence of threshold events. For example, in western Canada, significant warming over the past 100 years at stations has been accompanied by earlier dates of last spring freeze, later dates of first fall freeze, and a longer frost-free period [F7-5]. In western Lower Michigan, the average date of last spring freeze has occurred earlier as springtime temperatures have warmed [F7-6]. The complex relationship between means and threshold events may be the result of concurrent fluctuations in the mean and variance of temperature series. Recent research suggests that the frequency of extreme events is relatively more sensitive to changes in variability than in the mean, and that this sensitivity is greater the more extreme the event [F7-8]. Consequently, a decrease in variability could offset any increase in mean temperature, and conversely, an increase in variability could lead to more frequent occurrences of threshold or extreme events even with little or no change in mean temperature.

Current Assessment

The impact of climate change on fruit production in the Great Lakes region was recently evaluated using VEMAP data from the CGCM1 and HadCM2 models valid at two locations on either side of Lake Michigan: Eau Claire, Michigan and Sturgeon Bay, Wisconsin. The VEMAP datasets from the corresponding coarse GCM output allowed a downscaling approach to determine more location-specific effects. The evaluation focused on low temperature thresholds including:

- 1) number of days with temperatures $\leq 32^{\circ}\text{F}$ during the calendar year
- 2) date of last spring freeze (defined as $\leq 32^{\circ}\text{F}$)
- 3) date of the first fall freeze (also defined as $\leq 32^{\circ}\text{F}$)
- 4) dates at which 270 (base 41°F) growing degree units (GDUs), an indicator of early bud development, and 540 (base 41°F) GDUs, an indicator of mature bud development, are reached
- 5) the heat accumulation at the time of the last spring freeze
- 6) percentage of years with freezing temperatures after 270 and 540 GDU accumulations are reached
- 7) length of the growing season (defined as the period between last spring freeze and first fall freeze)
- 8) base 41°F and base 50°F GDU accumulation during the growing season

Assessment Decade 2025-2034 Projections

The values at Eau Claire suggest that in 2025-2034 the growing season will increase by 12-20 days. The HadCM2 scenario points to a later date of first fall freeze as the primary contributor to a longer growing season, whereas the CGCM1 scenario indicates that an earlier date of last spring freeze will be responsible. The scenarios also suggest a 10-14 day decrease in the number of days with minimum temperatures $\leq 32^{\circ}\text{F}$. Plants are expected to reach critical growth stages as much as one week earlier in 2025-2034, and seasonal GDU accumulations are projected to be a substantial 11-23 percent larger than current values. The values for both scenarios are smaller at Sturgeon Bay where a 5-10 day increase in the growing season, a decrease of 2-8 days in the frequency of minimum temperatures $\leq 32^{\circ}\text{F}$, a 7-9% increase in seasonal GDU accumulation, and little or no change in the median dates of 270 and 540 GDU accumulation are projected. At both locations considerable ambiguity surrounds the projected changes in the overall susceptibility of fruit trees to damaging low temperatures. The HadCM2 scenarios suggest that susceptibility will be reduced. The CGCM1 scenarios project greater susceptibility. According to the CGCM1 scenarios, the amount of growth (e.g., heat accumulation) at the time of last spring freeze is greater than at present, and there is a higher probability, especially at Sturgeon Bay, of a freeze after reaching sensitive growth stages.

Assessment Decade 2090-2099 Projections

Large changes in the threshold parameters are suggested by the scenarios for the 2090-2099 decade. Projected changes are considerably greater for the CGCM1 scenarios compared to the HadCM2 scenarios. Also, the projected changes are larger at Eau Claire than at Sturgeon Bay. The dates of last spring freeze at the two locations are projected to occur between 17-36 days earlier than at present. The projected change in the date of first fall freeze is somewhat smaller, between 4-23 days, depending on which scenario and location. The HadCM2 scenarios suggest that critical growth stages will occur 11-16 days earlier, whereas the CGCM1 scenarios suggest a 9-27 day change at Sturgeon Bay and a much larger 41-45 day change at Eau Claire. The HadCM2 scenarios project that seasonal GDU accumulations at the two locations will be 20% larger than present-day values, and the CGCM1 scenarios project a 50% increase. Similar to the 2025-2034 period, the projections of overall suscep-

tibility to cold damage are contradictory with the HadCM2 scenarios for the two locations suggesting less susceptibility and the CGCM1 scenarios suggesting greater susceptibility.

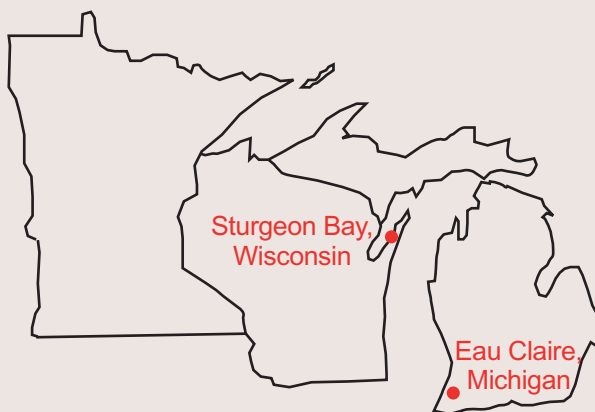


Figure F7.1: Recently evaluated VEMAP data using the CGCM1 and HadCM2 models at two locations: Eau Claire, Michigan and Sturgeon Bay, Wisconsin.

Summary

The analyses presented above for the period 2025-2034 suggest that the fruit-growing regions surrounding Lake Michigan will experience a moderate increase in growing season length and seasonal heat accumulation, and a decrease in the frequency of subfreezing temperatures. In

addition, important growth stages will occur earlier in the calendar year than at present. Very large changes in the threshold parameters are projected for the period 2090-2099, especially for the eastern shore of Lake Michigan. However, it is unclear for both periods whether fruit production will be more or less susceptible to damage from low temperatures after critical growth stages are reached. The projected changes in the threshold parameters presented here should be interpreted cautiously as the type of downscaling methodology and the GCM simulation to which the methodology is applied introduce considerable uncertainty into assessment studies. Generally, the projected changes for the stochastically-derived HadCM2 and CGCM1 scenarios are smaller than the changes projected by alternative scenarios [F7-9, F7-10].

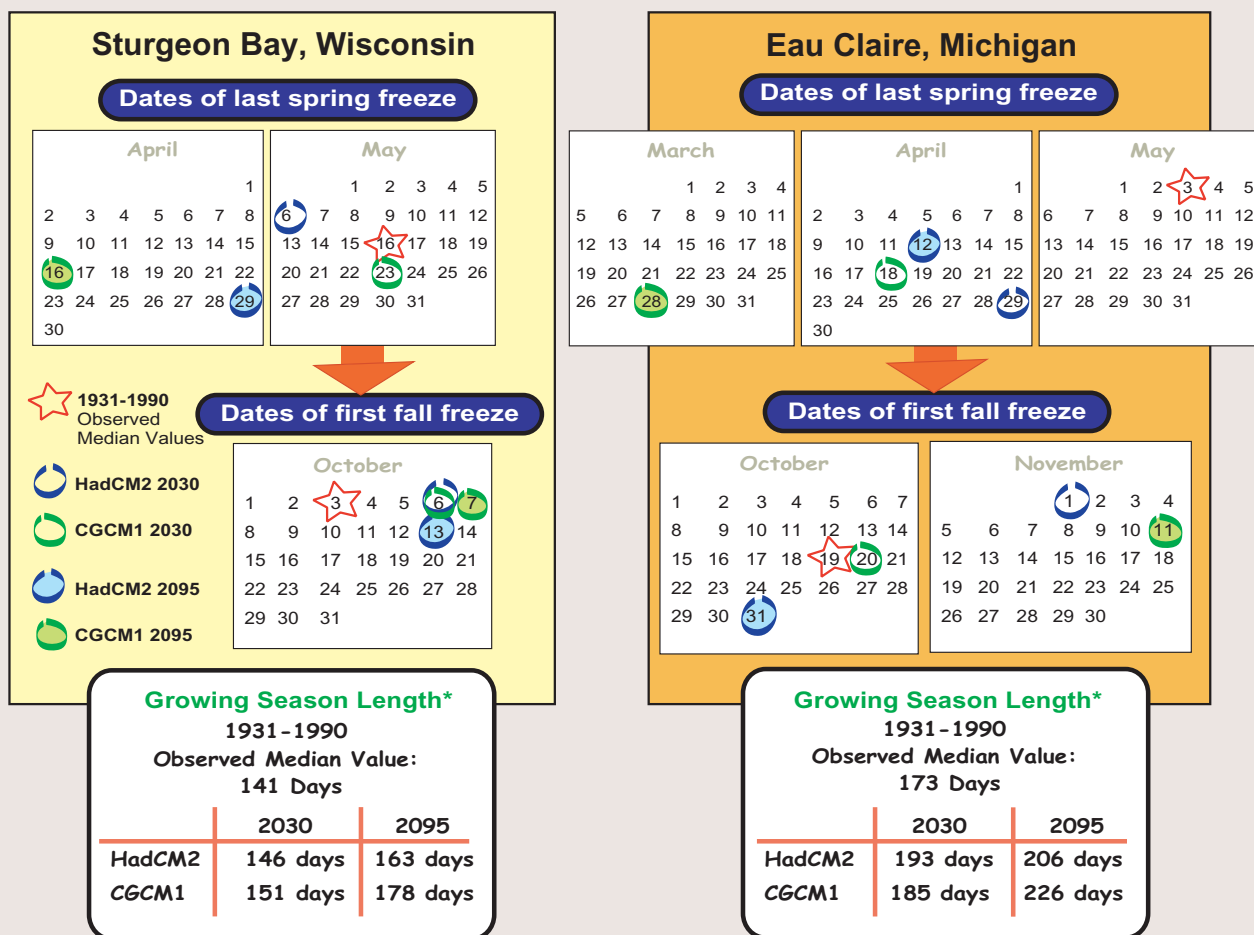


Figure F7.2: Median values of temperature threshold parameters for Sturgeon Bay, Wisconsin and Eau Claire, Michigan for the assessment decades of 2025-2034 and 2090-2099. Differences were calculated between the assessment decades and a control period of 1994-2003. These differences were then compared to the observed median values for 1931-1990.

* Growing season length was calculated for each year separately, and the median value was determined from the values for each year. Consequently, the change in the growing season length does not necessarily equal the sum of the change in the dates of last spring freeze and first fall freeze.

8. QUALITY OF LIFE

HUMAN HEALTH

study conducted by

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Current Stresses

Heat-related Morbidity or Mortality

A variety of weather phenomena can cause injury and death to humans. People who lack protection to extremely hot or cold weather will eventually suffer from disturbances of normal physiological functions. Exposure to extreme, prolonged heat is associated with cramps, fainting (syncope), heat exhaustion, and ultimately heat stroke. Within limits, however, what is meant by “extreme” is somewhat relative, partly depending on previous exposure, physiological adaptation, age, and other health conditions. Furthermore, the impact of temperature extremes depends on the length of time that people have been exposed to local conditions, socioeconomic status and ability to cope, genetic predispositions to various conditions, and various physiological factors [8-1]. Some “heat waves” may last for a few days or for weeks, but the difference can influence how people with previous exposure or social conditions respond. Long or repeated heat waves may not allow people’s bodies to recover from the heat. Also, since heat waves often occur with little or no rain, high humidity, elevated ozone, and other air pollutants (NO₂, SO₂, and particulates), susceptibility to these conditions also will affect health outcomes.

Climate change impacts on human health in the Great Lakes region are likely to be greatest in urban areas, especially where extremely high temperatures historically have been rare. For example, July 1999 was the hottest on record in New York. As many as 70 people died in Chicago during a 1999 summer heat wave with temperatures reaching 99°F [8-2]. But, heat waves are not new to Chicago. In 1995, more than 700 (most of them elderly) died from exposure to extreme heat. The impact from heat stress can be minimized through appropriate behavioral adaptations, e.g., using air conditioning, wearing light clothing, and maintaining hydration. Perhaps more important than the daytime high temperatures are the high nighttime lows, particularly in urban areas. Because the poor, elderly, very young, and otherwise ill tend to be less able to withstand extreme temperatures, they are more susceptible to the effects of these extremes. In addition, persons who must work outside or who lack access to indoor cooling also are at greater risk.

Output from the HadCM2 and CGCM1 models was examined to see how high temperatures would increase from the present (e.g., 1975-1994) to the end of the 21st century (e.g., 2080-2100). Model-forecasted atmospheric thicknesses were used rather than model-forecasted high temperatures, based on the assumption that this deep tropospheric parameter is a more accurately-forecasted variable than surface temperatures and so is a better proxy for identifying extreme heat episodes in GCMs. The results from both models for the warm season (May 1 – October 31) are shown in Figure 8.1. The CGCM1 model suggests a significant increase in days above 90°F – while the HadCM2 model suggests a more modest increase. Additionally, the distribution of temperatures in the HadCM2 model is broader than that in the CGCM1. Interestingly, both models suggest a decrease in interannual variability – in contrast to the popular notion that weather may become more variable.

Severe Weather Events

In addition to extreme temperatures, other impacts from short-term, extreme weather events such as floods, tornadoes, and blizzards, may affect health. In the Great Lakes region, heavy precipitation events have increased in frequency over the last 100 years. Both the HadCM2 and CGCM1 suggest these will continue to occur with increasing frequency. Unlike the prolonged periods of extreme heat that gradually cause death, extensive precipitation producing floods can cause immediate injury and death. Future changes in other extreme weather events are difficult to assess. The historical record indicates a slight decrease in thunderstorms for the Central US and a significant increase for the entire US in tornadoes over the last 50 years [8-3]. Because a tornado has to be seen before it can be counted, these numbers may be skewed by increasing population density. Additionally, GCM limitations (e.g., in resolution), preclude an ability to assess whether frequencies or intensities of these types of (small scale) extreme weather events, such as severe thunderstorms or tornadoes, will change. Even if such events decrease (slightly) in frequency, they will likely continue to cause more property damage because of increases in population, wealth, and inflation that will likely continue. Indirect effects from wind, flooding or drought may also produce longer lasting and further reaching impacts on housing, food

production, drinking water, and social infrastructure. The extent to which such events will harm people's well-being largely depends on early warning and disaster preparedness.

Air Pollution and Respiratory Diseases

Another possible impact of climate change and variability on health in the region involves the air that we breathe. Many forecasts suggest increases in ground level air pollutants, some of which may exacerbate asthma and other respiratory illnesses and tax cardiac function [8-4].

Local levels of gases such as sulfur dioxide, nitrous oxides and ozone, as well as various kinds of aerosolized particulate matter already have been increasing in some areas. In addition, warmer weather can enhance fungal spores and pollen, which in turn may increase allergic reactions. As with most possible health impacts, the association with climate is not well understood, making forecasts of future risk is uncertain. In the Great Lakes region, air pollution associated respiratory disease has not been well studied. Results suggest that air pollutants are but some of many factors involved in the etiology of respiratory diseases. Furthermore, different studies have produced inconsistent results.

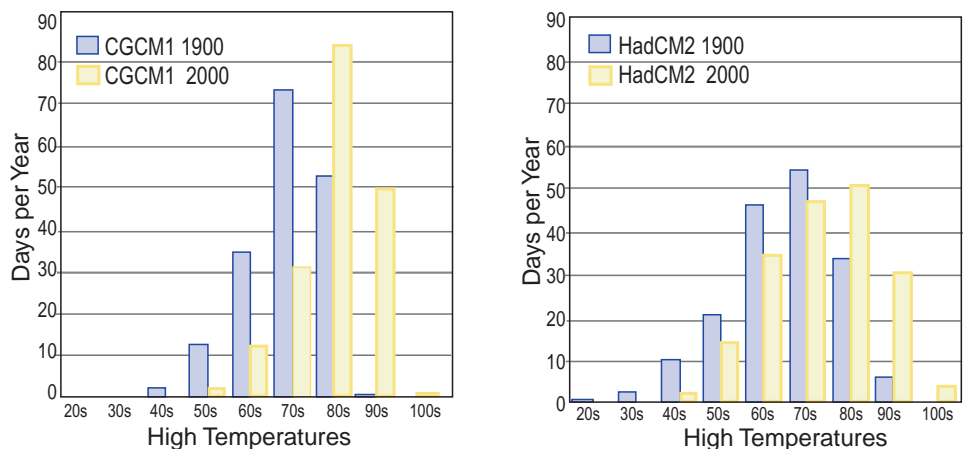


Figure 8.1: Annual GCM-derived distributions of days with high temperatures per year for the warm season (May – October) for a current 20 year period (labeled 1900) and for a future 20 year period (labeled 2000). For the CGCM1 model (left) the current period is 1975-1994 and the future period is 2080-2099. For the HadCM2 model (right) the current period is 1970-1989 and the future period is 2078-2097.

A simple analysis of the output from the CGCM1 and HadCM2 models suggests that the number of days with synoptic patterns that are conducive to high ozone will increase by the end of this century. High ozone days are basically characterized synoptically by southwesterly flow, high pressure (e.g., anti-cyclonic flow), and high heat (e.g., temperatures above 90°F). Table 8.1 shows how the number of days when all three conditions exist simultaneously will increase for Detroit, Michigan – primarily as a result of more days with high heat.

Infectious Diseases and Weather Variation

Many impacts of climate change on infectious diseases have been suggested. New studies are currently underway to examine whether temporal variation in incidence of selected infectious diseases is related to that of temperature, precipitation, and other weather variables [8-5]. In collaboration with the Michigan Department of Community Health, case data from 1984 through 1998 are being studied using time-series analysis. County-specific data for reported cases of aseptic meningitis, hepatitis A, and salmonellosis have been transferred and organized for initial study. Possible links to climate are suggested for all three diseases since the temporal pattern of each is strongly seasonal and there is considerable variability from one year to the next. However, before more extensive time-se-

ries and autocorrelation analysis can be undertaken, the data must be adjusted in various ways. First, local, point source outbreaks must be considered and possibly eliminated. Second, GIS-based mapping by county shows that there is considerable variability among regions, suggesting that analysis by subregions may be needed. In that case, weather data from stations within each region will be used in conjunction with synthetic monthly average data to search for temporal patterns. Finally, it may be necessary to calculate age-specific incidence rates since each disease has more cases in certain age groups and the proportion of the population in each age group may differ among regions and over time. Once these adjustments have been made, it will be necessary to search for patterns of association over time that might demonstrate occurrence of excessive cases following unusual weather patterns. In addition to these diseases, similar analyses of cases are planned for cryptosporidiosis, giardiasis, histoplasmosis, influenza, and leptospirosis, among others.

Coping Strategies

Responses to various health threats posed by climate change will vary considerably depending on the etiology of each condition [8-6]. Extreme heat-associated morbidity and mortality is well understood and technically easy to prevent. If increased extreme heat events were to occur in the future, then a combi-

<i>Model</i>	<i>Years</i>	<i>Southwest flow</i>	<i>High pressure</i>	<i>High heat</i>	<i>High ozone</i>
Current 20-year period					
CGCM1	1975-1994	1570	2205	10	3
HadCM2	1970-1989	1295	2162	140	22
Future 20-year period					
CGCM1	2080-2099	1603	2171	987	377
HadCM2	2078-2097	1254	2167	582	157

Table 8.1: Total number days with favorable synoptic conditions for high ozone during the warm season (May – October), in Detroit, Michigan . For the CGCM1 model the current period is 1975-1994 and the future period is 2080-2099. For the HadCM2 model the current period is 1970-1989 and the future period is 2078-2097.

nation of improved forecasting, information distribution, and special assistance to high risk populations should compensate for most of the increased risk. Physiological adaptation is possible over a period of years, but since most stress occurs during short-term extreme events, this may not allow for such adaptation. Improved economic well being and education of urban poor and elderly would allow these groups to better cope through increased use of fluids and air conditioning.

Other extreme events such as tornadoes or floods demand better forecasting and advance warning, but responses depend more on preparedness and disaster relief than individual behaviors. Preventing construction of dwellings on flood plains, improving the construction of houses, and enhancing knowledge of responses to extreme winds or floods should help to reduce impacts from these events. Unusual precipitation that may not produce catastrophic flooding yet may impact on infectious diseases can be addressed with a combination of improved storm drainage systems, and warnings to avoid high-risk areas. The impacts of air pollutants on health can be decreased if susceptible people are given warning of severe conditions. The elderly or those with preexisting respiratory conditions may be warned to minimize time spent outdoors during the stagnant air conditions associated with increased ground level air pollutants. In extreme cases, the only response may be to move from more polluted urban areas, or even to leave the Great Lakes region entirely for less polluted and less humid climates.

The climate link to variability in infectious disease risk is different for each disease, but appears to be important for certain diseases. Most are highly seasonal, suggesting that normal variation can be foreseen and appropriate warning made. A few such diseases (e.g. influenza, rabies, Lyme disease) have effective vaccines, which can be obtained prior to exposure. Others have known behaviors associated with risk, making education and behavior changes the most effective response. For example, risk of most vector-borne diseases of the region (e.g. Lyme disease, Eastern Equine Encephalitis, etc.) can be reduced significantly by changes in activity, clothing, or housing, so

that responses mostly involve education. Finally, many of these diseases respond to post-exposure antibiotics, permitting treatment that is usually curative.

Information & Research Needs

The difficulties, inadequacies, and uncertainties in both the forecasts of possible climate change and the effects on public health demonstrate that major research efforts are needed to better understand and develop eventual mitigation strategies [8-7]. Diverse biological and physical systems, the long time during which processes are likely to occur, and the uncertainty inherent in these interactions all suggest that research has become vitally important, yet extremely difficult. More research is needed, but so is a shift in the kinds of investigations. At present, systematic, long-term surveillance data on many diseases is inadequate to permit rigorous study of historical patterns. Many of the important interactions involve diverse variables that range from physiology to economic policy, from microbiology to social behavior. New theory and analytic tools are needed that not only incorporate such interactions, but also analyze climate variability as part of a much larger arena of environmental change, that considers human disease as part of political ecology.

Long-Term Monitoring and Analyses

As many recent reports have argued, the problem of emerging diseases, disease surveillance in the US, and surveillance assistance to other countries are woefully inadequate. Without systematically gathered epidemiological records, the basic information needed to track and retrospectively analyze changes in disease patterns is lacking. Disease gathering in the Great Lakes region differs among cities and states, making some surveillance data difficult to interpret. These data are critical to studies aimed at understanding disease trends, analyzing retrospectively changes associated with the environment, and eventually modeling future outbreaks and situations of high risk. Such data is vital for developing casual hypotheses and is the

best way to test these predictions prospectively. In addition to the important role that surveillance plays in recognizing new and emerging diseases, surveillance data is essential to the study of climate impacts on health.

Environmentally-Based Research and Evaluation

Another new research emphasis could focus on identifying and understanding disease-specific environmental factors that can be used to prevent outbreaks before they occur. Climate variables are among many such environmental factors. In the Great Lakes region, well-designed experiments are needed to explore how multiple variables interact, and how diverse climate conditions impact on their interactions. Classical laboratory experiments aimed at demonstrating dose-response or transmission of infectious agents cannot fully replicate the diverse conditions that occur under natural climate variation. Unfortunately, an increasing focus on simple experiments that produce rapid results has meant that long-term prospective observations have declined. Other experiments that evaluate how changing environments may lead to rapid evolution will enhance understanding of when adaptation may occur in the face of gradual climate change during the next century.

Multidisciplinary Perspectives and New Analytic Techniques

Not only must the extent and coverage of observations be improved, but new methods for gathering or analyzing data and interpreting patterns are also needed. The complex interactions among physical, biological, and socioeconomic variables that determine disease risk suggests that more multidisciplinary studies are needed. In addition to the traditional disciplines such as climatology, immunology, or physiology, the determinants of health outcome involve sociology, psychology, and economics, etc. Thus, new methods are needed that could include theoretical studies of complex dynamic behavior, spatial statistical investigations of disease ecology during environmental change, or integrative modeling of socioeconomic development impacts on pathogen transmission. Studies of multivariable interactions that may have spatio-temporal fluctuations, nonlinearities, thresholds, or time-lags will require different conceptual foundations and new analytic tools. Methods for studying interactions among qualitatively different kinds of variables are needed to address the complex processes that occur as climate change impacts on health. More simulation modeling involving socioeconomic and behavioral adaptation will be particularly instructive.



RURAL LANDSCAPE

study conducted by

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Significant changes have occurred in the rural areas of the Great Lakes region during the last few decades. Two trends in landuse can be identified that have relevance to this change. The amount of land under cultivation decreased from 1987-1997 by 5%. At roughly the same time (between 1980-1993) forest cover increased 3% (Chapter 6). In combination, the pressures of rural development and the urbanization of formerly rural lands (in many cases prime agricultural land) are dramatically changing the face of the region's landscape.

Current Stresses

The two main stresses are sprawl and climate change. The most significant current stress to the rural landscape is the urbanization and general sprawl of population beyond the traditional boundaries of the large metropolitan areas. For instance, while the traditional metropolitan areas of Milwaukee and Detroit have either lost population or held steady, the surrounding rural areas have dramatically increased in the classification of urban land that was formerly rural.

The negative aspects of this trend are considerable. They affect energy consumption by increasing commuting and home heating requirements. They affect runoff by decreasing vegetation, increasing pavement and other hard surfaces, and introduce new pollutants (lawn fertilizers, automobile emissions etc.) into the nearby watercourses and airsheds. They

threaten local wetlands with increased runoff and pressure from contractors and developers seeking to increase buildable lots. They require additional infrastructure in the form of roads, water, sewer, and energy delivery systems that require construction and disruption of local landforms and ecosystems.

Not all of the rural development is simply from families escaping the traditional urban neighborhoods. It also represents the trend of "rural sprawl" which marks the trend of aging baby boomers, desire to retire and vacation near bodies of water. While vacationers once traveled to relatively primitive cottages near lakes and rivers "up north" in the Great Lakes region, now vacation residences of 2000 square feet complete with the "urban yard ethic" are commonplace beyond the traditional suburban areas near major metropolitan centers [8-8].

Good examples of this type of threat include the Lake Superior shoreline in northern Wisconsin and the Lake Michigan shoreline around Grand Traverse Bay and the Leelenau Peninsula in northern lower Michigan. Where "... all the best sites already sprouting seasonal and permanent homes, developers went to work on 'marginal' lands — sites with steep slopes, adjacent to large bogs or wetlands, shallow weedy bays, poor access, or terrain that block a view or access to the water [8-8]." People are willing to travel farther and farther for a larger home on a smaller lot.

Grand Traverse County is another region experiencing the effects of rural sprawl. Here in the Cherry Capital of the World the year-round population of 90,000 swells to 2 million in the summer with the influx of seasonal visitors and tourists [8-9]. It is also a prime place for retirees. A recent national survey placed the region as number 8 in a list of the nation's Top Ten places for retirement. Human waste disposal alone has become a prob-

lem of epidemic proportion. Local septic systems designed for less intense and less frequent use have become almost universally overloaded. Consequently, the flows of nutrients and pathogenic bacteria have increased – both into the local ground and surface water. Temporary strategies for managing this additional waste have been further jeopardized by insufficient capacity for the treatment of septage (pumped material from septic tanks) at the few local sewage treatment plants. So traditional strategies of “pump and treat” for the septic needs of lake homes can no longer be predictably undertaken [8-10]. The sudden need to expand sewerage service to many new residents and visitors has taxed municipal budgets. The problem will probably continue for the foreseeable future.

Of course, all of these pressures lead directly to the degradation of the attractive features of the rural landscape that attracted the population shift in the first place. The challenges of managing growth in areas facing both urban and rural sprawl are significant and currently occupy a great deal of planning and political effort.

Climate Change and Related Stresses

The current stresses on the rural landscape are already significant. Climate change in the form of increased temperatures and anomalous severe weather events will serve to further challenge a landscape that is already in the process of profound change.

Some examples of exacerbated change that might be expected include the following:

- Higher water temperatures in combination with development-related storm water management issues (e.g. increased runoff, greater concentrations of pollutants, decreased buffering capacity from wetlands) will increasingly stress fish stocks and decrease the attractiveness of lakeside or riverside home ownership for some.

- Climate-related lowering of lake levels will have a dramatic effect on shoreline [8-11]. In some cases, this will result in reclamation of beach areas (primarily around the Great Lakes) but in other cases it will make real estate along lower inland lakes and rivers less attractive.
- Challenge to arboreal forests from both the warming of the climate and development will lead to further forest loss and species weakening.
- Rural parcelization will reduce of migration pathways for both plant and animal species that become challenged by warming and development could have a dramatic effect on the ecosystem’s ability to relocate and recover from warming.

A third stress comes from the non-indigenous species that have entered the Great Lakes region for hundreds of years. The harmful species quickly take hold often without any natural predators. The results can be costly to the economy and the environment. Probably the most destructive invader in the region’s waterways is the sea lamprey. Millions are spent annually to reduce their populations, for left uncontrolled, sea lampreys can decimate fish harvests – from 17 million pounds to virtually zero [8-11]. On land, the gypsy moth caterpillar is well known in many forests. In Michigan, large forest tracts have been defoliated [8-12]. Many trees in the region are favored by the caterpillar including oak, aspen, birch, basswood, tamarack and apple. Usually, if the forest is healthy, the trees can survive a gypsy moth attack. Unhealthy trees will die because of the fungal disease and insects that descend on the forests following a gypsy moth attack.

It seems that the greatest effect on the rural landscape is the current trend of sprawl – whether it is urban or rural. While climate change will no doubt worsen the effects of this trend, it also seems clear that the primary driver is sprawl.

Coping Strategies

During a review of the current stresses and impacts of future climate change, a number of critical areas were identified that might need extra special coping strategies. Some of these strategies include:

- 1) Public programs for purchase of greenspace and wildlife corridors
- 2) Investment in rural sewerage services, particularly around developed rivers and lakes
- 3) Consistent zoning approaches to encourage minimum impact development, and
- 4) Stronger enforcement of existing wetland and stormwater runoff requirements



RECREATION AND TOURISM

study conducted by

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Recreation and tourism in the Great Lakes region incorporates a variety of activities ranging from outlet mall shopping to ice fishing. Some of the activities that were reviewed with particular attention for this study include: fishing (both inland and lake); snowmobiling; skiing; pleasure boating; leaf peeping; bird watching; hiking; sightseeing (driving); hunting; gambling; and shopping. The region's significant natural beauty and cultural features combine to attract tourists from all over the Midwest.

Current Stresses

Tourism is an important portion of the region's economy. However, it also has significant stresses with which it is already coping. Some of these stresses are specific to the industry and others are specific to the region.

Industry Specific Stresses

Perhaps the greatest current stress to the tourism industry is its own inherent instability. Tourism is primarily a service industry that is seasonal and highly dependent on low wage and benefit-free positions to staff its busy times at both eating and lodging establishments. Economic prosperity or woe during any given season is frequently dependent on normal weather fluctuations and other variables like gas prices and general consumer confidence. For instance, skiing and ski

resort operation in the Great Lakes is more economically threatened by small snowfall fluctuations than its competitors in the Far West. So, relatively minor changes in snowfall can significantly reduce skiing days and total industry revenue generation.

Region Specific Stresses

Regionally specific current stresses to the economy include ongoing water quality concerns about the Great Lakes (primarily Lakes Michigan and Erie) and continuing difficulties with the influx of invasive species. Both of these factors negatively affect the attractiveness of the biggest resource in the region—the Great Lakes. There are clear linkages between water quality and the appeal of water recreation. Areas that are perceived to be contaminated because of lowered water quality may reduce the attractiveness of fishing and pleasure boating. Additionally, tourism in the region continues to grow significantly across the board. This in turn is leading to resource overuse and will ultimately lessen growth of this sector unless additional resources (hotel rooms, campsites etc.) can be developed in response to demand.

With the exception of tourism drops in Minnesota during 1992-93 due to flooding and an exceptionally cold summer, the region has seen healthy growth in tourism during the 1990s. Even issues of concern like Great Lakes water quality have shown improvement from their difficulties twenty years ago [8-13].

Climate Change Related Stresses

Climate change in the form of rapidly rising temperatures over the next century will likely have significant effects on tourism in the upper Great Lakes region. Consider the following effects:

- Lengthened Tourist Season – Higher average temperatures translate into longer tourist seasons in the fall and spring. It is likely this will result in a longer season, especially in the fall, with increased economic activity.
- Warmer Lakes/Rivers: Reduced Fish Stocks – Both diversity of fish and total amount of fish is likely to decline as lakes and streams warm between 4-14°F [8-11].
- Great Lakes Whitefish – Less ice cover could cause rapid decline in whitefish population because of increasingly unprotected spawning areas
- Leaf Color Viewing Reduction – Higher temperatures (which may challenge species by pushing them beyond their preferred climate envelope) suggest a reduction of the quality of the leaf-related color tourism in the region through premature leaf fall off and overall species die-off [8-15].
- Winter Sport Reduction – Reduced ice coverage and snow depth will harm the ice fishing, snowmobiling and skiing industry [8-16].
- Increase in Exotic Species – Because colder winter temperatures have kept some of the exotic species at bay, increased temperature could greatly increase invasion of exotics [8-14].

It seems likely that a superposition of the impacts of climate change on top of current stresses will ultimately result in the greatest impacts. Therefore systemic responses will be the most important to understand and project. For instance, the combination of climatically challenged ecosystems within the most popular tourist destinations in conjunction with increased tour-

ist pressure could result in sudden and dramatic degradation of the sensitive ecosystems. In the long run, significant degradation of the region's tourist attractions could have economic consequences.

Similarly, increased development pressure in rural areas, particularly in areas around inland lakes and rivers, has led to more concentrated and more polluted storm water run-off. The added effect of dramatic warming of these water bodies will then more quickly drive the cold and cool-water species out of existence. Alleged replacement of these fish stocks with other angler-friendly species (e.g. walleye, pike) remains for the most part unsubstantiated.

Coping Strategies

During a review of the current stresses and impacts of future climate change a number of critical areas were identified that might need extra special coping strategies. Some of these strategies include:

- 1) Examine ecosystems carefully for stress impacts to look for indicators that growth and warming will have compounding negative consequences;
- 2) Manage tourism growth in areas that will benefit from climate change and in areas that will be hurt. For example, make sure that facilities are sufficient to take advantage of longer warmer summers while helping communities that are hurt by losses in winter sports;
- 3) Create policy initiatives that offset economic dislocation in areas and populations especially hard hit by the negative effects of lost tourism through climate change.

Closing Remarks

A GLIMPSE OF WHAT'S TO COME...?

This report has presented some of the latest research regarding how climate may change in the Great Lakes, and how that change may affect the people, plants, birds, fish, and other animals that live in the region. When we began this assessment with a workshop in 1998, many of the impacts we described for participants seemed far-fetched: Lake levels could fall so low they would interfere with recreational boating. In 1996 the lakes were near their record highs. Winter sports might be affected by winter warming . . . in Minnesota? As impossible as our scenarios may have seemed at the time, we have had to deal with such conditions in the past few years. While we cannot say that we were right about climate change, or that conditions won't swing back to "normal," we can learn from the experience of dealing with the impacts we've faced recently. While the greatest climate changes and their impacts may not appear in the region until later this century, temperatures and precipitation have been increasing slowly throughout the Great Lakes over the last hundred years. More significant changes have occurred lately that are consistent with our findings. Just in the last ten years, much above-normal temperatures and wide variations in precipitation have had both negative and positive impacts on many aspects of life. The aim of this report, and of the entire National Assessment Process, is to identify the potentially significant impacts and to inform the public and policy-makers of those impacts so they can minimize the negative ones and capitalize on the positive ones.

For example, the Midwest heat waves that occurred during the summer of 1995 killed over 700 people in Chicago. Most of the deaths occurred during a single heat wave in July. Over 160

people died in one day alone — shortly after the heat index exceeded 115°F on two consecutive days. That hot summer highlighted the need to be better prepared for future heat waves — particularly in urban areas of the Great Lakes region and especially because they will likely occur more frequently - as noted in this report.

Just a couple of years after the 1995 summer heat wave came the most intense El Niño ever recorded. Many of the Great Lakes States experienced one of their warmest winters ever and well-below normal snowfall. Although revenue at Midwestern ski resorts was down, snow removal and road maintenance costs were also down. The two winters after that, 1998-99 and 1999-2000, were influenced by La Niña and even though cooler and wetter than normal conditions were expected, the weather in the Great Lakes remained mild and had additional effects on the regional economy.

The above-normal temperatures and the reduced ice-cover over the last couple of winters, and the below-normal precipitation and above-normal evaporation over the last couple of years have led to some of the lowest lake levels being recorded on the Great Lakes in recent history. By spring 2000, lake levels on Lakes Michigan and Huron had dropped nearly three feet below chart datum. The sharp drops sent a wake-up call to residents regarding the significant impacts on commercial shipping, recreational boating, and drinking water quality — to name a few. The low-level, ice-free conditions on the Great Lakes over the last couple of years have provided an interesting situation for Great Lakes shippers — preventing them from carrying their normal-weight loads, but allowing them to ship goods for longer portions of the year.

Lake levels are a lynchpin for many other sectors of life in the Great Lakes. When they are low, impacts extend beyond creating difficulties for people involved in commercial shipping and recreational boating. For example, the number of ponds this spring dropped more than 40% from numbers last year (1999), and 20% below the long-term average (1974-1999). The reduced pond numbers, water levels, and below-normal precipitation this spring led to a slightly lower population of breeding ducks this spring, according to the US Fish and Wildlife Service's annual survey of key nesting areas for breeding ducks. There was an overall decline of 4% in breeding ducks – from 43.4 million to 41.8 million. Breeding populations of mallards fell 12% to 9.5 million.

Finally, a very early warm spell this year (Spring 2000) across the region led to the earliest spring bloom ever recorded. Temperatures hit 80°F on March 1st across much of Michigan – the earliest ever in the year to reach that temperature. A cold snap that followed threatened to be costly for many cherry growers in Michigan, but the actual damage was not bad. The early start to the growing season this year is an example of exactly what is expected to happen with climate change.

This report represents an attempt to better understand the massively complex earth-atmosphere-ocean system, and how climate change will influence all aspects of life. The report is based on output from some of the latest and most sophisticated General Circulation Models. These models now have the capability to simulate with reasonable accuracy the interactions between the oceans and the atmosphere, the transfer of heat and moisture between the ground and the atmosphere, and cloud development. Although the models are not perfect, there are several rea-

sons to believe that the impacts we have projected from their future scenarios will occur. First, the models have accurately recreated current conditions, which is in itself an accomplishment given the fact that the model simulations begin in the year 1900 (i.e. one hundred years ago). Second, simulations from different models are reasonably consistent in their future projections of wind patterns, storm frequencies and intensities, and temperature and precipitation changes. Third, a collection of recent impacts has occurred across the region that is consistent with many findings in this report.

An important spin-off of this report has been an opportunity for us to develop the knowledge, the tools, and the teamwork within the Great Lakes region so that when even more accurate climate and impacts models are developed, the infrastructure will be available to take better advantage of the more accurate information. An important aspect of the infrastructure is getting more stakeholder participation. In fact, in addition to informing the public of the possible impacts of climate change on the Great Lakes region, we hope this report will motivate stakeholders to get involved in the assessment process – to help guide our research, to answer questions of greatest concern to the public, and even to help conduct future assessments. Assessment is a process, and the Great Lakes assessment will continue to evolve to respond to stakeholder interest and to better scientific information and models.

Additional information on how to get involved and future climate impact assessment activities for the Great Lakes region is available on our web site: <http://glra.engin.umich.edu>.

Appendix A

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