WISCONSIN'S CHANGING CLIMATE:

IMPACTS AND ADAPTATION

The first report of the Wisconsin Initiative on Climate Change Impacts

2011

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Wisconsin Initiative on Climate Change Impacts
2011

THE NELSON INSTITUTE
FOR ENVIRONMENTAL STUDIES
University of Wisconsin-Madison
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Wisconsin Initiative on Climate Change Impacts

WISCONSIN DEPT. OF NATURAL RESOURCES

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SUMMARY

Wisconsin's climate is changing. A wealth of temperature and precipitation data provide evidence that on average our state has become warmer and wetter over the past 60 years. Scientists project that the decades ahead will bring changes in climate much more profound than those already observed; in some cases those changes could occur more rapidly than plant or animal species can adapt. This first report from the Wisconsin Initiative on Climate Change Impacts (WICCI) seeks to identify the impacts of those changes as well as the strategies needed to adapt to them.

Historical temperature and precipitation patterns have varied widely across regions of the state, especially when seasonal differences are factored in. For instance, in the 1950-2006 period used in this report, **winter** temperatures increased significantly in northwestern Wisconsin, and these increases extended into the central part of the state. Springtime temperature increases also occurred in the same regions. During winter, nighttime minimum temperatures warmed at a faster rate than daytime maximum temperatures, and the number of very cold nights declined significantly. Northwestern and central Wisconsin experienced 14 to 21 fewer nights with temperatures below zero degrees Fahrenheit. Other areas of the state saw reductions in subzero nights of seven days or less.

During **summer** months, daytime maximum temperatures across the state changed little from 1950 through 2006, but nighttime minimum temperatures warmed significantly in the northwestern and central regions. Similarly, the number of days when temperatures exceeded 90º F did not increase throughout the state. Autumn temperatures did not warm statewide; northeastern and southwestern Wisconsin actually cooled slightly during the fall.

Precipitation also varied widely across the state, with localized drought in some northern regions and much wetter conditions in western and south central Wisconsin. Statewide, average annual precipitation increased by about 15 percent from 1950 through 2006. In some regions, including south central and western Wisconsin, annual precipitation increased by as much as seven inches. In areas of northern Wisconsin, however, declines of up to four inches were recorded.

Future projections of temperature and precipitation patterns for Wisconsin were created by University of Wisconsin-Madison climate scientists using 14 "downscaled" global circulation models. Their work indicates that **Wisconsin's warming trend will continue and increase considerably** in the decades ahead. By the middle of the century, statewide annual average temperatures are likely to warm by 6-7º F.

By mid-century, seasonal temperature increases (above current conditions) are projected to be greatest in winter, followed by spring and fall, then by summer. For example, wintertime temperatures are likely to increase by about 8º F, with slightly warmer temperature increases in northwestern Wisconsin. Summertime average temperatures are likely to rise 5-6º F statewide, with the greatest warming in northern Wisconsin. In addition to this warming, the number of summer days that exceed 90º F is projected to increase statewide. Southern and western regions of Wisconsin could see three or more weeks per year of these very hot days, while northern regions are likely to see an increase of about two weeks. A smaller increase in the number of hot days is projected for the areas along Lake Superior and for Wisconsin's "thumb" in Lake Michigan due to the cooling effect of the Great Lakes. Consistent with these warming trends, the number of winter nights below 0º F is projected to decrease significantly across the state by mid-century. A decline of about three weeks of these cold nights is expected in northern Wisconsin, with about one fewer week in the southeastern counties.

While our future precipitation patterns are more difficult to discern than temperature, the state is likely to continue its trend toward more precipitation overall, with the most probable increases in winter, spring and fall. Large storm events are also likely to increase in frequency during spring and fall. Statewide, the amount of precipitation that falls as rain rather than snow during the winter is also projected to increase significantly, and freezing rain is more likely to occur.

Rising air temperatures, shifting precipitation patterns and increases in heavy rain events lead to a variety of secondary effects on our natural and built environments. These changes bring impacts at both broad and local levels, affecting the state as a whole as well as individual species of plants, fish and wildlife, and human communities.

The **quantity and quality of Wisconsin's water resources** are influenced by climate change. For example, we are seeing a decrease in the length of time that ice covers our lakes. A detailed examination of ice records for Lake Mendota in Dane County shows that the annual duration of ice cover has declined by about a month over the last 150 years. Water levels are higher in many areas due to increased precipitation but lower in the north due to a prolonged drought. With evapotranspiration rates projected to increase in the future, water levels in northern lakes and wetlands could decline further during future periods of drought, such as the droughts that have occurred periodically during the past century. More runoff from projected heavy seasonal rainfalls will likely increase sediment and nutrient inputs to lakes and wetlands, leading to more blue-green algal blooms in lakes and loss of biodiversity in wetlands. Changes in the timing and amount of rainfall influence groundwater recharge, and any decrease in groundwater recharge could be compounded by increased demand for irrigation due to an extended growing season, shifts in the timing of precipitation, and high temperatures or regional droughts.

Natural habitats respond to a changing climate in many ways, with impacts seen in wildlife, forests and plant communities. Plant hardiness zones are shifting; consequently, the ranges for many plant and animal species are expanding northward. An earlier onset of spring will disrupt relationships between plants and pollinators and could cue reproduction or other lifecycle events at non-ideal times. Species currently found in northern Wisconsin at the southern edge of their range may no longer be able to survive in the state, while more southerly species, including those not currently present in the state, will expand northward. Animals like the American marten, spruce grouse and snowshoe hare may disappear from Wisconsin. Boreal tree species such as black spruce, balsam fir and paper birch may no longer grow in the state by the end of century, resulting in a dramatic change in the tree composition of our northern forests. Due to slow dispersal rates or fragmented habitat, migration of certain species to fill these northern voids is not certain.

Rising stream temperatures, which result from rising air temperatures and other factors, will lead to reduced habitat for native brook trout that require cold water. Scientists project that if summer air temperatures rise by 5° F, brook trout habitat will decline by 95 percent across the state. However, a warming climate will benefit other species, including the gray squirrel, white-tailed deer, European starling and Canada goose, with potential negative impacts on the environment resulting from increases in their populations.

Lower soil moisture levels are another change related to increased temperatures and evapotranspiration rates. Reductions in soil moisture affect numerous amphibians across the state such as frogs and salamanders that need moist conditions to survive. All of these changes could reduce biodiversity in Wisconsin and weaken the resilience of many ecosystems.

Wisconsin's agriculture will also be affected by climate change. In general, research suggests that warming temperatures in spring and fall would help boost agricultural production by extending the growing season across the state. However, increased warming during the summer months could reduce yields of crops such as corn and soybeans, with studies suggesting that every 2° F of warming could decrease corn yields by 13 percent and soybean yields by 16 percent.

The projected precipitation trends of more annual rainfall and more intense storms heighten the potential for significant **soil erosion**. Most soil erosion occurs during the few heavy rainfall events that occur each season, and an increasing number of these storms are likely in our future. This is especially true during the spring months, when cultivated fields are mostly bare with little plant cover to reduce soil erosion. Without appropriate adaptation measures, future precipitation patterns could double soil erosion rates by 2050 compared to 1990 rates. The good news is that Wisconsin farmers and natural resource managers have effective conservation practices at hand, and widespread implementation has the potential to counter the threat of soil loss from climate change.

Wisconsin's **coastal regions** face new challenges as reduced ice cover, declining lake levels and increasing wind strength over the Great Lakes will bring impacts including increased shoreline erosion and recession and an increase in the vulnerability of shoreline infrastructure. Coastal wetlands face increased sedimentation from runoff and flooding and greater threats from invasive species that take hold when an ecosystem is disrupted or warmed. Lake Michigan's average water levels are expected to decline by about a foot by the end of the century. However, both high and low water levels will continue to impact coastal wetlands, bluffs and beaches due to natural fluctuations in water levels that occur every few decades.

Climate change also affects **society and the built environment**. New or more severe public health challenges arise as heat waves become more frequent and climatic conditions boost air pollutants such as smog and particulate matter. In the Chicago area, not far from several southeastern Wisconsin counties, occurrences of ground-level ozone exceeding current air quality standards are expected to increase from the present average of about two days per summer to about 17 days per summer by the end of the century. Pollen production is increasing, as well. All of these air pollutants worsen asthma and other respiratory diseases.

Waterborne diseases may multiply because human pathogens are introduced into the environment when combined and sanitary sewers overflow as a result of heavy rainfall or groundwater infiltration exceeding the capacity of wastewater treatment systems. In many places, current infrastructure is not equipped to handle the projected increases in frequency of heavy storms and subsequent runoff. This increases the risk that stormwater management and drinking water systems will fail and flooding will damage bridges, roadways and urban areas.

Adapting to impacts requires us to take a comprehensive view of climate change in Wisconsin. Adaptation strategies presented in each chapter of this report illustrate alternative ways to avoid some of the worst outcomes and take advantage of benefits where possible. They are provided to help stakeholders take action to create resilience within natural and built environments, build capacity to make better decisions, improve the communication of climate science and projected impacts to stakeholders, and fill gaps in our knowledge of how natural and human systems respond to climate change.

As stakeholders determine which strategies will best achieve their goals, several **adaptation principles** may apply. These principles help identify which actions to implement first, the degree to which flexibility can be built into resource management practices, and whether some strategies will bring benefits regardless of how the climate continues to change. For example, they suggest that when vulnerability is high, it may be wiser to be safe rather than sorry. They remind us that variability in both time and space needs to be recognized; even within Wisconsin, changes and responses to impacts will differ across the state. Many place-based impacts present unique restrictions and circumstances for adaptation. For example, large cities and tribal lands cannot be moved to more favorable climates, and designated natural areas may no longer protect the species they were originally designed to protect.

This report is the first in a series that will provide an ongoing assessment of climate change impacts and adaptation strategies in Wisconsin. Even as we present this synthesis of the findings of the 15 contributing working groups, the groups continue to move forward with vulnerability assessments and identification of adaptation strategies, while WICCI continues to identify topics and areas in need of future attention.

If Wisconsin is to adapt successfully to current and future climate change, information about climate science, predicted impacts, types of adaptation strategies and means of implementing those strategies must reach local and state decision-makers. WICCI envisions a climate adaptation outreach model that supports managers of natural and human systems and other decision-makers in assessing vulnerabilities and evaluating risks from climate impacts. WICCI will continue to engage Wisconsin academic institutions, state agencies, local governments, professional associations, businesses and other organizations in a process of identifying climate adaptation strategies. Outreach activities will also provide information on climate risk and adaptation to communities to support implementation of climate adaptation strategies. This report builds a foundation for long-term integration of climate risk education into Wisconsin's professional and community development efforts. To meet these objectives, WICCI will collaborate with existing education and outreach groups and support integration of information about climate impacts and adaptation into existing and new outreach programs.

An appendix includes the executive summaries of the technical, scientific working group reports, which are available in full on the Web at www.wicci.wisc.edu. The executive summaries contain the main findings of each working group along with key figures. Please see the full working group reports for information on methods, results and citations.

Wisconsin is a mosaic of forests, grasslands, hills, plains, farms and communities, endowed with thriving natural areas, agricultural lands and urban environments. The Great Lakes frame our northern and eastern borders, the Mississippi River hugs us to the west, and miles of streams and rivers dissect the landscape, itself dotted with thousands of inland lakes and wetlands.

Wisconsin's climate is changing consistent with changes occuring at the global scale, but those changes vary from region to region across the state. This report focuses on the impacts of climate change on a broad range of Wisconsin's human and natural systems.

Climate change affects Wisconsin's natural, social and economic environments. We need to adapt to the impacts that are occurring today and prepare for those that are likely to occur tomorrow. While people have always adapted to changes in their environment, the rate and scale of the changes we are seeing today – and those projected for the next century – require us to be more intentional and systematic in our adaptation strategies and plans. The Wisconsin Initiative on Climate Change Impacts (WICCI) seeks to identify climate impacts, vulnerabilities and risks and to develop adaptation strategies to build our state's resilience, prepare for or prevent negative consequences, and seize opportunities that may arise.

THE WISCONSIN INITIATIVE ON CLIMATE CHANGE IMPACTS

The Wisconsin Initiative on Climate Change Impacts (WICCI) is a statewide collaboration of scientists and stakeholders formed as a partnership between the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison and the Wisconsin Department of Natural Resources. Since its formation in the fall of 2007, WICCI has grown to include representatives from other state and federal agencies, several UW System schools, tribal organizations, businesses and nonprofit groups totaling more than 70 collaborating entities.

WICCI comprises a science council composed of a diverse group of scientists from a range of disciplines that oversees 15 working groups, which are in turn made up of experts from a variety of fields; an advisory committee of stakeholders from the public and private sector; an outreach committee; and an operations unit.

The goals of WICCI are to:

- **Assess and anticipate climate change impacts upon Wisconsin's natural and built environments.**
- **Evaluate risks and vulnerabilities within our ecosystems, infrastructure, industries, agriculture, tourism and other human and natural systems.**
- **Recommend practical adaptation strategies and solutions that businesses, farmers, public health officials, municipalities, resource managers and other stakeholders can implement.**

Please see www.wicci.wisc.edu for more information.

INTRODUCTION

Wisconsin's Changing Climate: Impacts and Adaptation is the first in what will be a series of climate impact and adaptation reports by WICCI. This report is the first step in what will be a long-term, collaborative process to prepare Wisconsin for the changes ahead and to preserve our natural resources, our economy and our enjoyment of all that our great state has to offer.

This assessment of climate impacts in Wisconsin is written for Wisconsin policy-makers, managers and decision-makers in governmental bodies at all levels, including the state, counties, cities and municipalities. It is also written for people and organizations whose businesses, farms, properties and special places have been or will be affected by a changing climate and for others interested in climate change and its potential impacts.

Throughout this report, contributing scientists look at our climate history to learn from our past and look to the future using state-of-the-art climate models. Wisconsin is diverse in its ecological and human landscapes, and climate change impacts vary across different areas. In order to develop effective adaptation strategies, we zoom in on each topic area, region or group of resources and then step back to look at how each part fits into the whole.

This report represents the work of more than 200 researchers, managers, educators and other experts with intimate knowledge of Wisconsin and its climate, waters, fish and wildlife, forests and other natural communities, cities and farms and public health. Fifteen working groups have assessed climate change impacts and developed adaptation strategies for various sectors of the state. Some working groups adopted broad purviews; others focus on specific issues or regions. In some topical areas, we have a wealth of data and working groups offer well-supported strategies. In other areas, the research is preliminary, and we are only beginning to know the right questions to ask.

WICCI is in the early phases of addressing these issues at the appropriate scales for planning and action. Successive assessments at four- or five-year intervals will keep us ahead of the many issues and concerns that will need to be addressed. As WICCI progresses in the years ahead, we anticipate more detailed climate projections upon which to build our assessments. We will broaden our research, adding topics and sectors, even as existing working groups continue to gather data, analyze impacts and make further recommendations. We will document our progress in future assessment reports.

Wisconsin's Changing Climate is organized into three main sections. Part 1: ***Changes*** details the science of climate change and introduces the concept of climate adaptation. Part 2: ***Impacts*** describes the impacts of climate change on various natural, cultural and economic resources in Wisconsin. Part 3: ***Actions*** provides a more comprehensive discussion of adaptation to climate change in Wisconsin, in which we look at the ways in which the adaptation strategies presented in each chapter fit together and overlap. We lay out a framework to move forward and implement adaptation strategies, and we touch on topics that we plan to expand as WICCI continues to study climate change impacts in Wisconsin.

Finally, an appendix includes the executive summaries of the technical, scientific working group reports. The executive summaries contain the main findings of each working group. The research, reports and documentation on which this assessment is based are available on the WICCI Web site (www.wicci.wisc.edu).

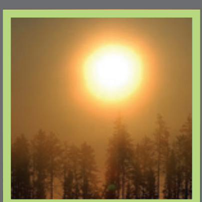
PART 1:

CHANGES

CHAPTER ONE

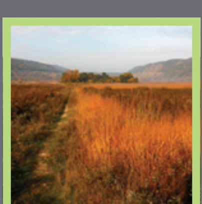
CLIMATE PAST.

Wisconsin's Recent Historical Temperature Trends



Projected Changes in Temperatures

Wisconsin's Recent Historical Precipitation Trends



Projected Changes in Precipitation

Wisconsin's climate is changing. A wealth of temperature and precipitation data gathered over more than half a century, along with records from a variety of other periods and sources, paint a consistent picture of our state becoming generally warmer and wetter. The decades ahead are likely to bring changes much more profound than those seen so far, according to climate models.

The warming Wisconsin has experienced to date is consistent with the global trend.

The warming Wisconsin has experienced to date is consistent with the global trend. The past three decades have been Earth's warmest since reliable surface temperature records began to be kept in 1850, with a global average increase of about 1.5 degrees Fahrenheit over that period (see figure 1). In fact, temperature trends based on Arctic ice cores and other evidence indicate that the Earth's temperature

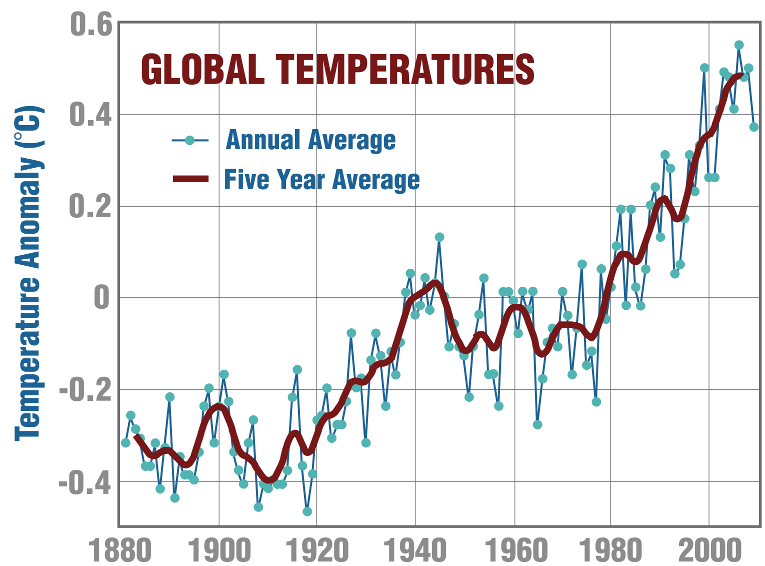


Figure 1. Global average temperatures have been steadily rising since reliable records began being kept in 1850.

Source: Intergovernmental Panel on Climate Change, 2007.

CHANGE IN WISCONSIN: PRESENT AND FUTURE

in the late 20th century may have been the highest in at least the last 1,000 years. Here in Wisconsin, our annual average temperature rose by about 1.1º F from 1950 to 2006, (figure 2), according to an analysis by scientists at the University of Wisconsin-Madison of daily measurements gathered from an extensive statewide network of weather stations.

While that one-degree increase in our statewide average might not seem significant, it coincides with the shorter length of time that our lakes remain frozen, the change in timing of some bird migrations, the emergence and flowering of certain plants, and other effects that indicate milder winters and earlier springs. Annual precipitation has also registered a modest increase, with 3.1 inches more per year, an increase of approximately 10 percent over the 57 years covered by the UW-Madison study.

The real story, however, is in the details. Wide variation is seen across regions of the state, especially when seasonal differences are factored in. Northwestern Wisconsin, for example, has seen a wintertime temperature increase of 4.5º F, while some parts of the state have actually cooled slightly in the fall.

Precipitation has also varied widely, with a localized drying trend in northern and northeastern counties and much wetter conditions in western and south central Wisconsin (figure 3).

What we have experienced so far may be a preview of what is likely to occur in coming decades. According to our state's best climate scientists – using the most recent computer models – Wisconsin's warming trend will not only continue, it will increase considerably by the middle of this century. Although future precipitation patterns are more difficult to discern, Wisconsin climatologists say the state is likely to continue its trend toward more precipitation overall, with the most probable increases in winter, spring and fall.

CHANGE IN ANNUAL AVERAGE TEMPERATURE (°F) FROM 1950 TO 2006

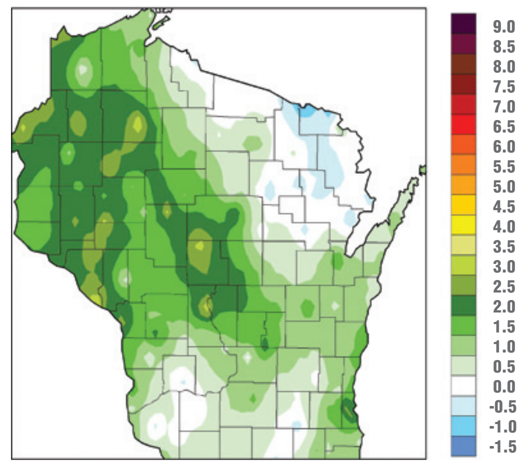


Figure 2. Wisconsin's annual average temperature has increased on average just over one degree statewide, with most of the increase experienced in the northwestern part of the state.

CHANGE IN ANNUAL AVERAGE PRECIPITATION (INCHES) FROM 1950 TO 2006

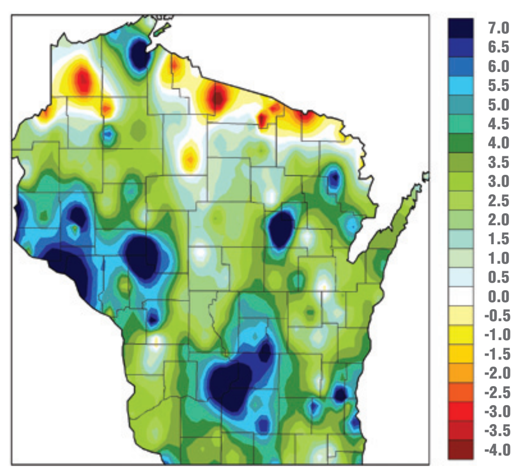


Figure 3. Overall, our state became somewhat wetter in the latter half of the 20th century, with much of the change concentrated in western and south central Wisconsin. Most northern counties became generally drier.

Wisconsin's Recent Historical Temperature Trends

Funded by a grant from Wisconsin Focus on Energy, scientists in the Nelson Institute Center for Sustainability and the Global Environment at the University of Wisconsin-Madison compiled daily temperature and precipitation readings gathered between 1950 and 2006 by a statewide network of 176 weather stations, part of the NOAA National Weather Service Cooperative Observer Program (figure 4).

While older data sets exist in some locations – Madison, for example, has weather information beginning in the 1870s – the starting point for the WICCI analysis is 1950 due to the reliability and consistency of weather station data from that point forward, allowing for the most robust scientific analysis.

Using this extensive body of weather data, the scientists found that, except for northeastern Wisconsin, most of the state has warmed since 1950. On a statewide annual average, the temperature has increased by 1.1° F, with the highest average warming of 2.5° F across northwestern Wisconsin. The greatest warming is occurring during winter and spring (figure 5), with

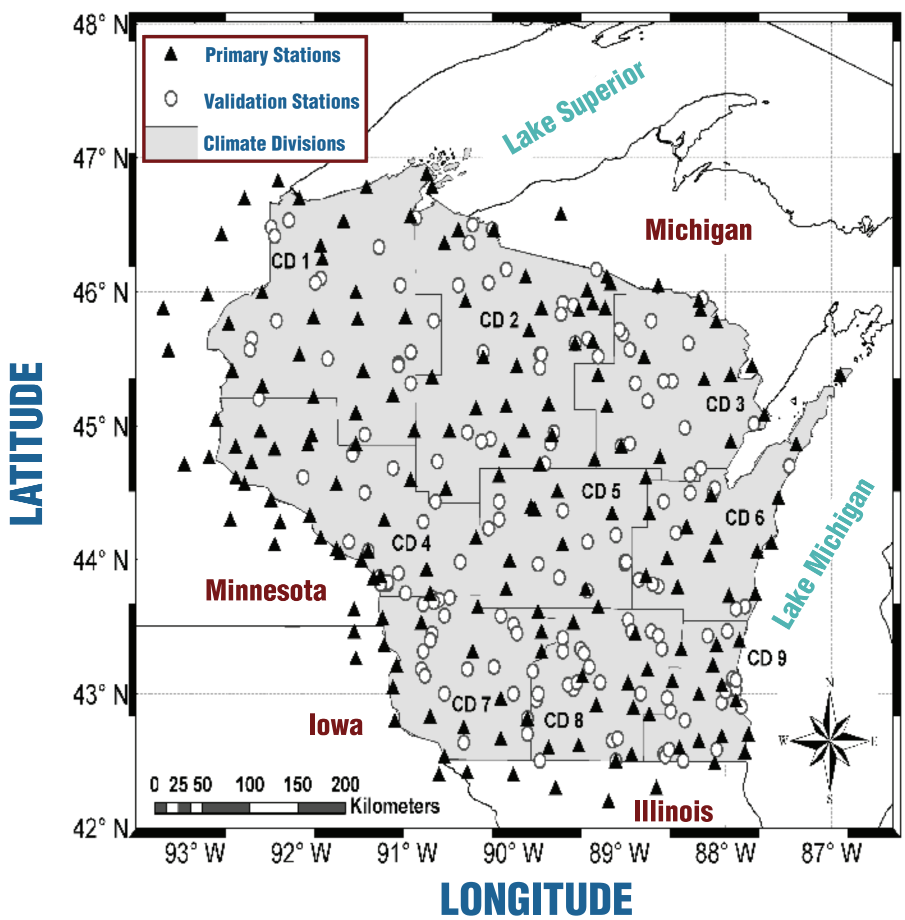


Figure 4. Daily temperature and precipitation data collected over more than five decades at scores of weather stations across Wisconsin were used to analyze the state's climatic trends since 1950. Stations in the neighboring states of Illinois, Iowa, Michigan, and Minnesota were included to help validate the Wisconsin data and identify errors and anomalies.

Source: Serbin, S.P. and C.J. Kucharik, 2009: Spatiotemporal mapping of temperature and precipitation for the development of a multidecadal climatic dataset for Wisconsin. J. Appl. Meteor. Climatol., 48, 742-757. ©American Meteorological Society. Reprinted with permission.




The greatest warming is occurring during winter and spring, with nighttime temperatures increasing more than daytime temperatures.

nighttime temperatures increasing more than daytime temperatures.

Winter: The observed warming since 1950 has been greatest in winter, with an average increase of 2.5° F across Wisconsin. The largest increase has occurred in northwestern Wisconsin, with an average increase of 4.5° F in some locations. In addition, the state is seeing fewer extended subzero stretches, and the nights have gotten milder.

Spring: Springtime average temperatures across Wisconsin have increased by 1.7° F since 1950, with increases of up to 3.5° F in the northwestern part of the state. In addition, most of the state has experienced a trend toward an earlier occurrence of the last spring freeze from two to 10 days, with the statewide average being 5.6 days earlier. In northwestern Wisconsin, the date of the last spring freeze has retreated by two weeks during just 57 years. Another significant change is seen in the official onset of spring (defined as the date at which daily temperatures have reached 50º F for 10 days running). The majority of the state – southwest of a line from Manitowoc to Ashland – has experienced an earlier onset of spring by this measure. The most significant changes have been found in the southern half of the state, where spring has been coming from three to 10 days earlier since 1950.

Summer: Since 1950, summer temperatures have increased by only 0.5° F when averaged statewide. The largest summertime warming has been 1.5-2° F over central and northwestern Wisconsin, while the remainder of the state has shown little change.

Autumn: Fall temperatures throughout much of the state have changed little since 1950 except for northeastern and southern Wisconsin, which have cooled by about 1.5° F. In spite of this small overall cooling pattern, the first fall freeze has trended toward a later date of occurrence in central, northeastern and northwestern Wisconsin, shifting from three to 12 days. Statewide, the first fall freeze averages 6.5 days later than it did in 1950.

WEATHER VS. CLIMATE

People often confuse *weather* with *climate*. These two words mean very different things. Knowing the difference can help us understand changes in climate that have already occurred and those that lie ahead.

Simply put, weather is the set of conditions happening at any time, or over relatively short periods such as days or weeks. We typically measure weather with instruments that record temperatures, humidity, rainfall, wind and other specific factors.

Climate is measured over much longer periods, most often on a scale of decades or more. Climate is the long-term average of weather conditions in a specific location. It is determined through statistical analyses of weather data collected over a long period of record.

An unusually heavy thunderstorm, a three-day snow event, three weeks of drought, an unusually hot summer or an unusually short winter are all examples of *weather*, which by themselves tell us little about *climate*. However, if those unusual conditions persist for long periods and cannot be explained by normal variability, it might indicate that a change in climate is taking place.

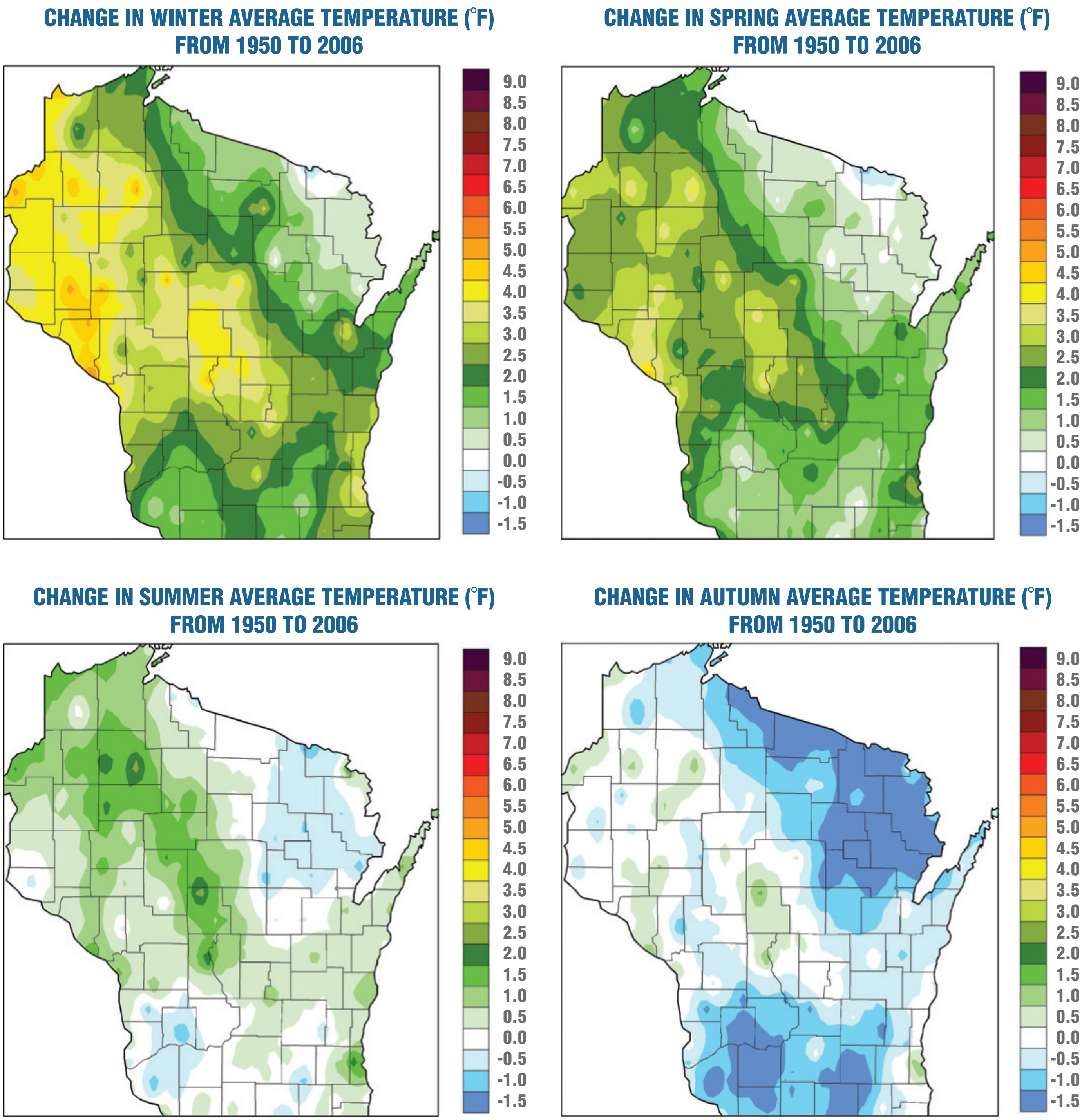


Figure 5. Wisconsin winters have warmed more than any other season in recent decades, especially in the north-western part of the state, where average temperatures have increased by as much as 4.5º F. Fall has seen a slight cooling trend.

Source: Kucharik, C.J., S.P. Serbin, S. Vavrus, E.J. Hopkins, and M.M. Motew. Patterns of climate change across Wisconsin from 1950 to 2006. Physical Geography 31, 1-28.

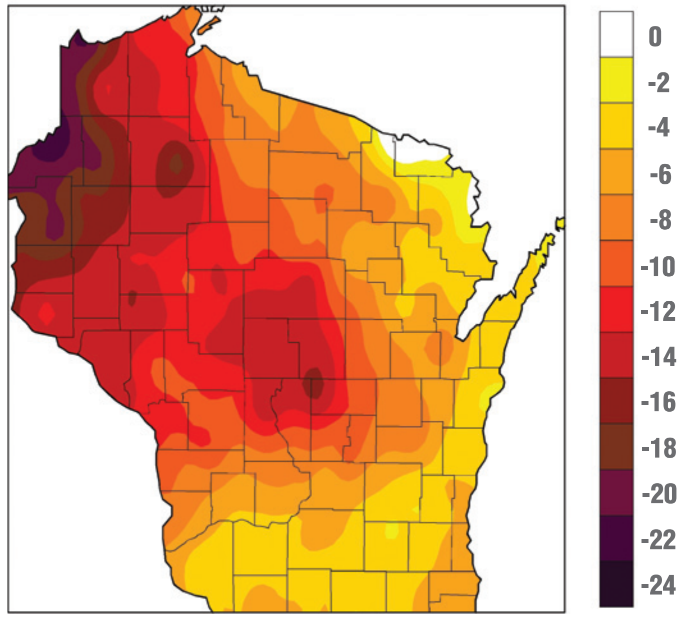
Extreme temperatures: From 1950 to 2006, the annual frequency at which daily low temperatures fell below 0° F diminished by about five days across southern Wisconsin and by 14 to 20 days across northwest-central Wisconsin, a 10-30 percent reduction in the number of extremely cold days each year. However, a consistent trend toward more frequent hot days was not seen in the record over that same period. The observed frequency of days over 90° F increased by two days per year across the northwestern portion of the state and decreased by two to four days per year over central and southwestern Wisconsin (figure 6).

WHY 1950 THROUGH 2006?

The historical analysis of Wisconsin's climate that forms the basis for this chapter includes the years 1950 through 2006. While researchers acknowledge that this 57-year span limits some of the conclusions that can be drawn, data from these years are the most complete for all the weather stations analyzed. By 1950, Wisconsin had established its dense network of cooperative observing stations (figure 4), allowing for the high-resolution spatial analysis by WICCI climate scientists.

While a handful of weather stations go back much further - for example, some observations from Madison date to 1869, and reliable Milwaukee data begin in 1929 - older data from these few stations, while suggesting variability in long-term climate, are too few to accurately show any of the long-term natural climate cycles that can affect our climate for decades at a time. The data period ends with 2006, the most recent year available to the climate scientists when the data were compiled. Future updates will extend the analysis to present.

CHANGE IN THE FREQUENCY OF NIGHTS BELOW 0°F PER YEAR FROM 1950 TO 2006



CHANGE IN THE FREQUENCY OF 90°F DAYS PER YEAR FROM 1950 TO 2006

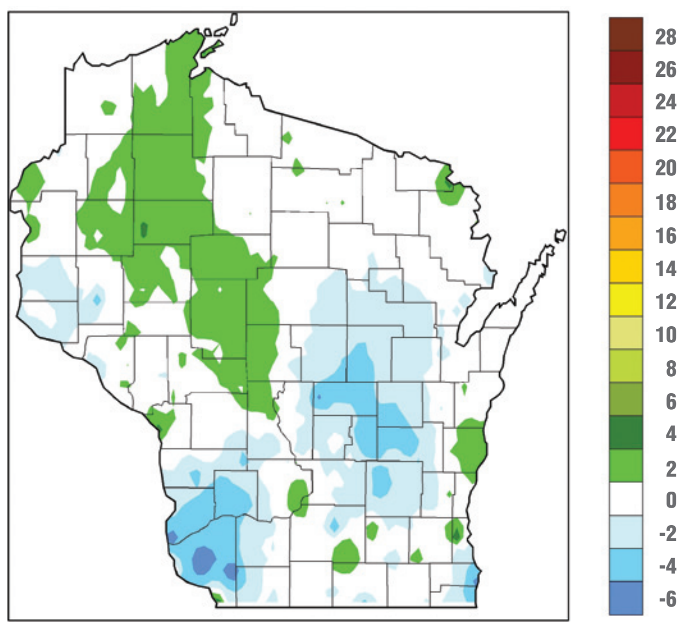


Figure 6. Consistent with the winter warming trend, Wisconsin experienced far fewer extremely cold nights between 1950 and 2006, especially in the northwest and central parts of the state. At the same time, extremely hot days did not significantly increase in number during summer.

Source: Kucharik et al., 2006.

CHANGE IN THE LENGTH OF THE GROWING SEASON IN DAYS FROM 1950 TO 2006

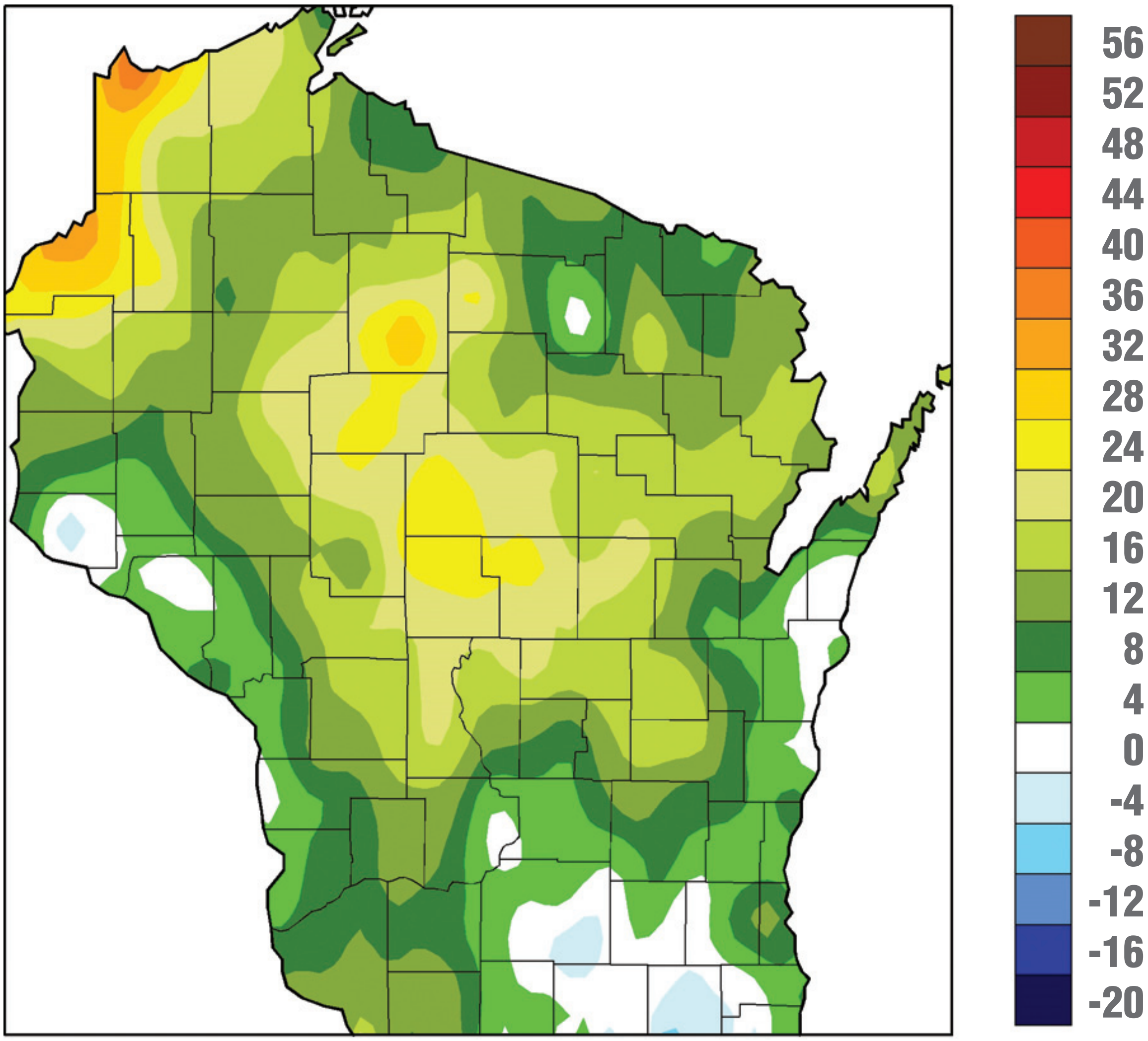


Figure 7. The length of the growing season has increased by as much as four weeks in parts of the state. (For this report, the growing season is defined as the number of days between the last spring freeze and the first autumn freeze, that is, when the daily low temperature falls below 32˚F.)

Source: Kucharik et al., 2006.

Growing season: The earlier spring and later fall freeze date trends have led to a significant increase in the length of the growing season in many locations (figure 7). The largest gains are located in the northwest and central regions, where the growing season has been extended by two to three weeks, with some counties in the extreme northwest seeing the growing season lengthen by about four weeks since 1950. The western counties near the Mississippi River, along with the south central, southeast, and east central counties, have not seen significant changes in the growing season length. While some counties along Lake Michigan, the Mississippi River and in southern Wisconsin have not seen a significant change in growing season, Milwaukee County's increased by approximately 10 days from 1950 to 2006. The statewide average increase in growing season length was 12 days.

Photo: Elizabeth Katt-Reinders

Projected Changes in Temperatures

Scientists in the Nelson Institute Center for Climatic Research at UW-Madison have developed detailed climate projections for our state over the 21st century. These projections use both large-scale information from climate models and local data drawn from the NOAA cooperative weather stations used for the historical analysis.

The researchers (funded by Wisconsin Focus on Energy) "downscaled" the global models to a localized grid of five-by-five-mile sections. This level of resolution improved the representation of water bodies, urban areas and other landscape features and enabled detailed analysis of locally projected changes and their potential impacts. The researchers used 14 different climate models and three different projections of future greenhouse gas emissions to quantify the range of possible future warming and precipitation for Wisconsin. The projections used in this report assume our continued reliance on fossil fuels, with carbon emissions remaining on a steady upward trajectory over the next few decades and carbon dioxide levels in the atmosphere rising from 390 parts per million today to 550 parts per million by the mid-2050s (figure 8).

The WICCI climate projection shows that Wisconsin's annual average temperature is likely to warm by 4-9° F by the middle of the century

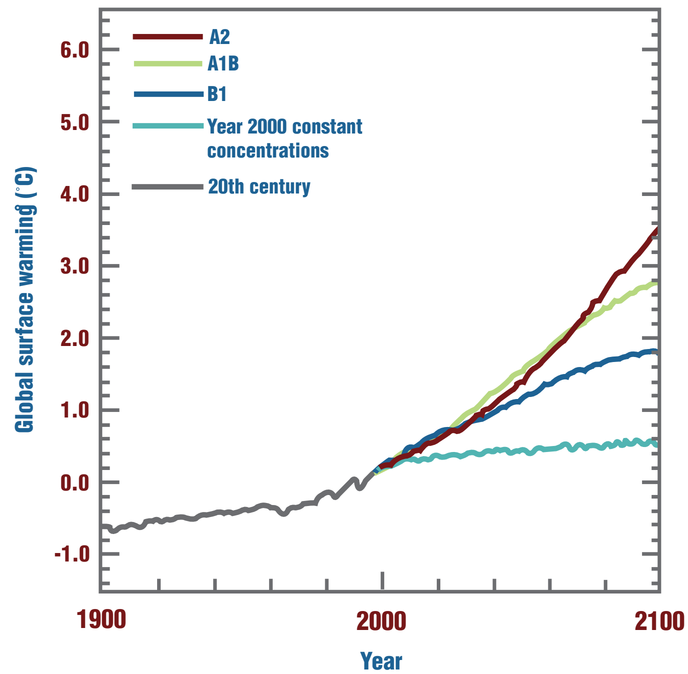


Figure 8. WICCI climate projections have been made using the A2 (high end), B1 (low end) and A1B (middle) carbon emissions scenarios developed by the Intergovernmental Panel on Climate Change. Projections shown in this report represent only the A1B scenario, which assumes continued reliance on fossil fuels.

Source: Adapted from Intergovernmental Panel on Climate Change, 2007.

Photo: Avery Dorland

The WICCI climate projections show that Wisconsin's annual average temperature is likely to warm by 4-9° F by the middle of the century (figure 9). Northern Wisconsin is projected to warm the most, with the least warming expected along Lake Michigan. Overall, the expected rate of warming is about four times greater than what we have experienced since 1950, and in keeping with the observed trend of the past half century, Wisconsin winter temperatures will continue to increase more than those of the other seasons.

Wisconsin winter temperatures will continue to increase more than those of the other seasons.

Winter: Wisconsin's future warming is projected to be greatest during winter, with increases of 5-11° F by the mid-21st century (figure 10). The largest increase is expected in northwestern Wisconsin. Overall, Wisconsin winters will be milder and shorter by an average of four weeks, with annual snowfall likely to decline by about 14 inches per year. The greatest snowfall reductions are projected for the flanks of the snowfall season in November and March-April as rainfall replaces snow; likewise, the largest projected decreases in Wisconsin snow depth and cover occur in February-March. The duration of a snow pack of at least one inch is projected to decline from the current average of 140 days per year to 116 days per year by the mid-21st century.

PROJECTED CHANGE IN ANNUAL AVERAGE TEMPERATURE (°F) FROM 1980 TO 2055

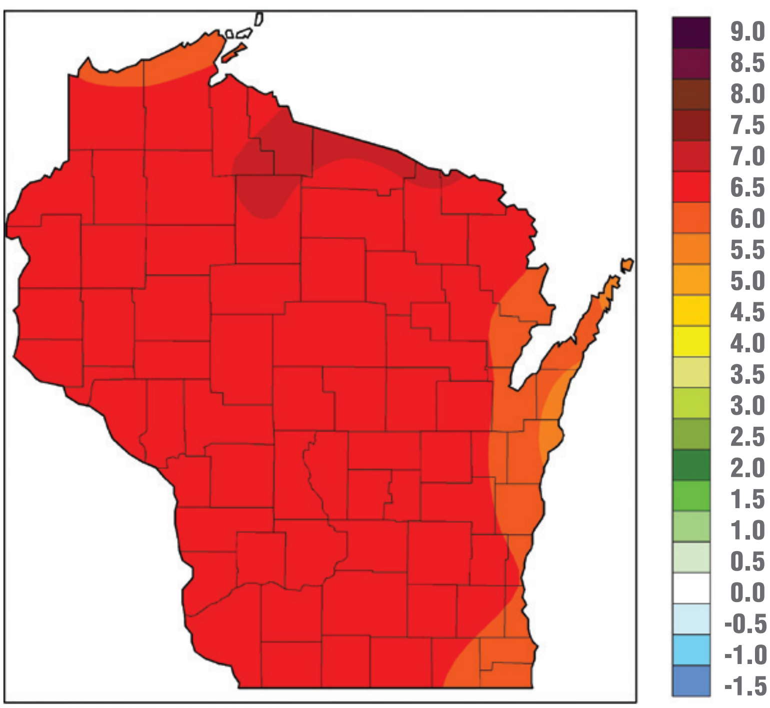
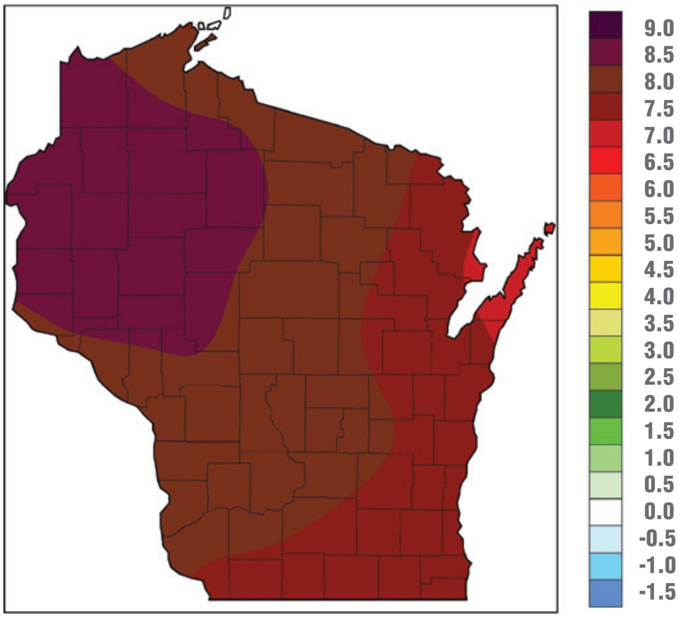
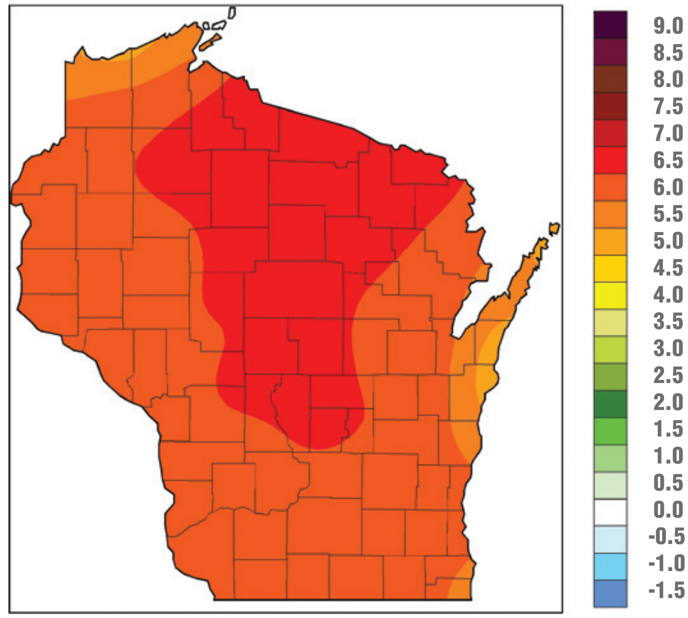


Figure 9. Climate models project significant warming across Wisconsin over the next few decades.

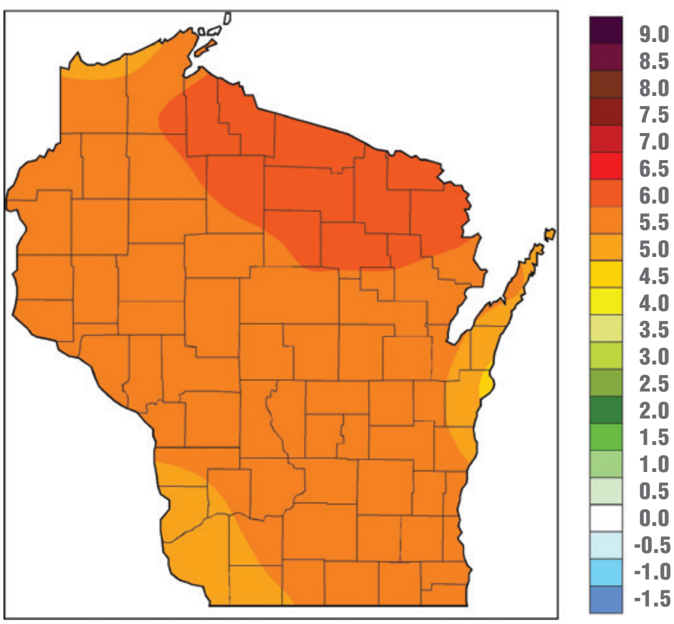
PROJECTED CHANGE IN WINTER AVERAGE TEMPERATURE (°F) FROM 1980 TO 2055



PROJECTED CHANGE IN SPRING AVERAGE TEMPERATURE (°F) FROM 1980 TO 2055



PROJECTED CHANGE IN SUMMER AVERAGE TEMPERATURE (°F) FROM 1980 TO 2055



PROJECTED CHANGE IN AUTUMN AVERAGE TEMPERATURE (°F) FROM 1980 TO 2055

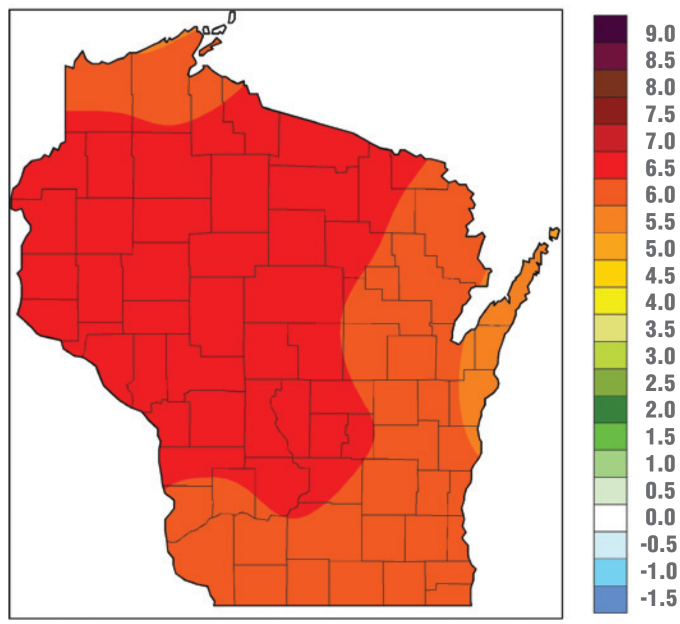


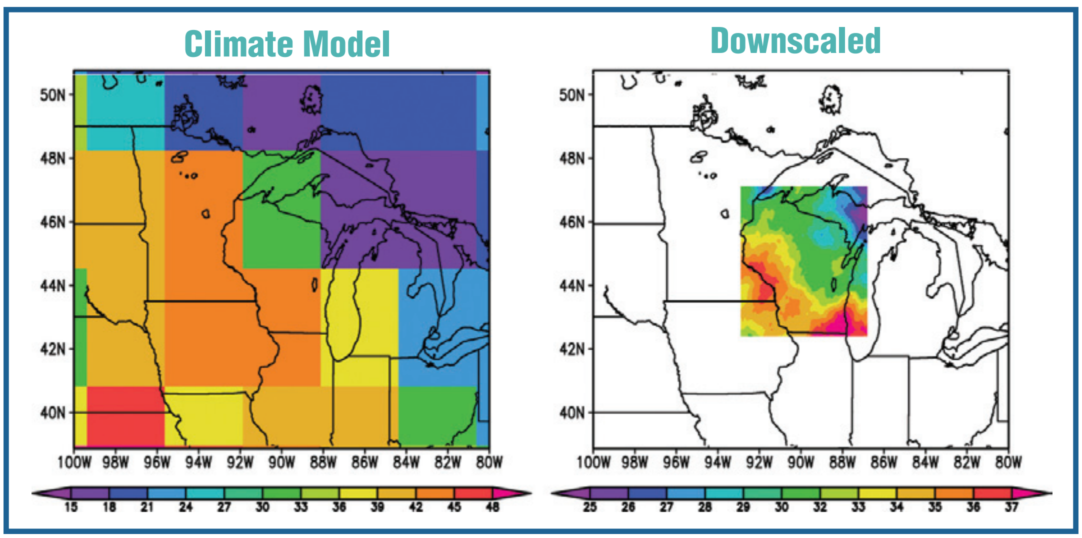
Figure 10. While all four seasons are expected to see large increases in temperature, the greatest warming is projected to occur during Wisconsin winters.

WHAT IS A CLIMATE MODEL?

A climate model is a complex set of equations representing the global climate system, including its physical, chemical and biological components. Referred to as General Circulation Models (GCMs), these models typically use supercomputers to simulate the interactions of the atmosphere, oceans, land and ice. They adhere to the basic laws of physics, fluid motion and chemistry to create a three-dimensional grid that depicts the major components and actions of the climate system.

The equations used to represent these basic laws of physics cannot solve the "problem" of the entire world climate. Instead, the world is divided into an array of grid boxes, and conditions for each box (for example, wind, ocean currents, temperature, moisture content, rainfall, etc.) are estimated for a period of time. The result is an estimate of global climate that is constrained by the fundamental physical laws that govern our climate system. The exact representations of each physical process differ between models, resulting in a range of plausible future climate scenarios. This range of plausible future climates is vital for informed decision-making and, as such, is an essential component of WICCI's efforts at projecting climate change.

For projecting future climates, these models include estimates of the changes in the atmospheric concentrations of greenhouse gases. For example, the A1B scenario is based on carbon dioxide levels rising from 390 parts per million today to at least 550 parts per million by the mid-2050s. Following the basic laws of physics, this increase will enhance the atmosphere's greenhouse effect, a fundamental reason why the models project a significant warming trend for the planet and many other physically related changes in the hydrological cycle.



Source: David Lorenz, Nelson Institute Center for Climatic Research, University of Wisconsin-Madison

Climate models can depict large-scale trends, but they are limited in what they can tell us about conditions at smaller scales, like a county in Wisconsin. Each grid unit on a global model typically covers several hundred square miles, which does not allow detailed analysis at a local or even state level. To overcome these limitations, UW-Madison climate scientists used a technique known as *downscaling*.

Downscaling is a way to derive locally relevant projections from global models using a statistical method. The method involves relating large-scale variables derived from global models to local-level climate conditions. Once these relationships have been developed and tested on past and current climate conditions, they can be used to project climate change locally from the global models. The UW-Madison climate scientists used the historic Wisconsin climate data analyzed in this report to develop and validate their technique.

Spring: Springtime temperatures are projected to increase by 3-9° F by the mid-21st century, with the largest increases across northern and central Wisconsin.

Summer: Climate models show that Wisconsin's warming is projected to be weakest in summer, with increases of 3-8° F by the mid-21st century and greatest across the northern part of the state.

Autumn: Wisconsin autumns are projected to warm uniformly across the state, with an increase in the range of 4-10° F by the mid-21st century.

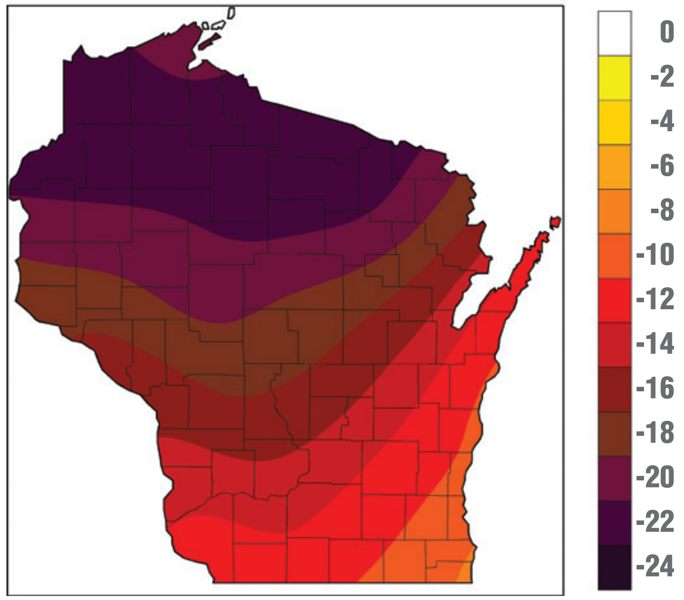
Extreme temperatures: Climate models project significant changes at both ends of the state's temperature spectrum. Today, daily high temperatures exceed 90° F about 12 times per year in southern Wisconsin and five times per year in northern Wisconsin. By the middle of this century, the frequency of very hot days will likely more than double to about 25 times per year in the south and 12 times per year in the north. That translates to about one to four more weeks each year with daily high temperatures topping 90° F.

> Our state will experience as many as three fewer weeks each year during which temperatures fall below zero.

At the same time, winters will continue to shift toward fewer extremely cold nights. Between 1950 and 2006, northern Wisconsin averaged 40-45 days when the temperature dropped below 0° F; southern Wisconsin experienced about 15 such days on average. Daily low temperatures below 0° F are projected to be much less common, ranging from six fewer subzero nights in southeastern Wisconsin to 22 fewer in the north. In other words, our state will experience as many as three fewer weeks each year during which temperatures fall below zero (figure 11).

Growing season: The projected warming across all seasons in Wisconsin implies that the recent historical trend toward longer growing seasons will continue. By mid-century, the last spring frost and first fall frost are

PROJECTED CHANGE IN THE FREQUENCY OF NIGHTS BELOW 0°F PER YEAR FROM 1980 TO 2055



PROJECTED CHANGE IN THE FREQUENCY OF 90°F DAYS PER YEAR FROM 1980 TO 2055

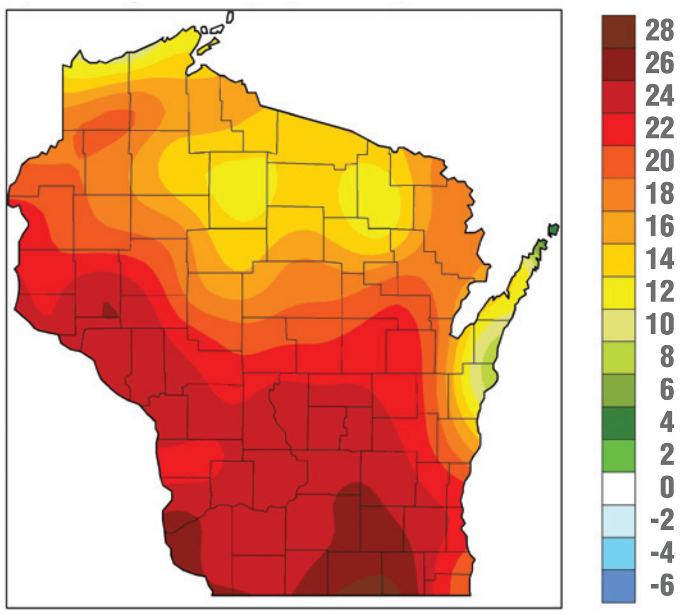


Figure 11: Wisconsin is likely to see fewer very cold nights and many more hot days in the decades ahead.

expected to diverge by four weeks, lengthening Wisconsin's growing season by a full month over the current averages (130 days in the north and 160 days in southern Wisconsin). In addition, the plant hardiness zones defined by the U.S. Department of Agriculture are likely to change. Wisconsin's plant hardiness zones currently range from a low of 3b in Washburn County to a high of zone 5b in Milwaukee County. By mid-century, warming will likely shift hardiness zones to growing conditions typically found one or two zones farther south, with Washburn County warming to zone 4b and Milwaukee County becoming zone 6a. (Please see Chapter Five for a more detailed discussion of the growing season.)

A NOTE ABOUT THE MAPS OF PROJECTED CHANGES

A key element of this assessment report is the use of probabilities in describing climate change in Wisconsin. The maps of projected changes used throughout this chapter represent the averaged findings from the 14 global circulation models on which the projections are based. These models indicate a range of possibilities for the state's future climate. The more the models agree on a particular result, the more confident scientists are that it will occur. Thus, the maps used here roughly represent the 50 percent probability level in each case – that is, there's a 50 percent probability that the changes could be greater than depicted by each map and a 50 percent probability that they could be lesser.

As another example, the projection that Wisconsin's annual average temperature is likely to warm by 4° - 9°F by the middle of the century represents a quantifiable range under the probability-based approach developed by WICCI climate scientists. In other words, there is a 90 percent probability that the warming will be greater than 4°F and a 10 percent probability that it will exceed 9°F; the maps roughly depict the mid-point of that range.

NATURAL CYCLES AFFECTING WISCONSIN'S CLIMATE

The global climate is driven by a very complex relationship between the ocean and atmosphere, including a number of natural cycles that occur on timescales of years, decades or longer. The best-known of these is the El Niño/La Niña-Southern Oscillation, or ENSO, a warming and cooling pattern that occurs across the tropical Pacific Ocean roughly every three to seven years. ENSO is characterized by variations in ocean surface temperatures in the tropical Pacific, which can create atmospheric effects leading to floods, droughts and other weather disturbances in many regions of the world.

Other natural variations occur on even longer time scales. For example, the Pacific Decadal Oscillation (PDO) is similar to ENSO but tends to vary on a much longer time scale. This manifestation of natural climatic variability occurs in the North Pacific and is associated with climate variations over North America. According to scientists, two "cool" PDO periods occurred from 1890-1924 and 1947-1976, while "warm" PDO periods occurred from 1925-1946 and 1977-1996. Other natural variations include the North Atlantic Oscillation or Arctic Oscillation (AO), which also is associated with temperature and weather variations over North America.

Many of these long-term variations affect Wisconsin's climate and must be accounted for when identifying possible climate change. According to the U.S. Global Change Research Program, "Estimates can now be made as to how each of these oscillations contributes regionally to the recent wintertime warming trend. For example, average wintertime temperatures for the period 1988 through 1997 have been warmer than normal for the whole U.S., with anomalies of over 1 degree C (1.8º F) for much of the country, and anomalies on the order of 1.5 degrees C (2.7º F) for the upper Midwest. The predominately warm phase of the AO during this period contributes to the warming over much of the country, with the strongest impacts located in the upper Midwest."

Climate scientists consider these natural cycles and their interaction with longer-term changes in climate, including those caused by greenhouse gas emissions.

Wisconsin's Recent Historical Precipitation Trends

From 1950 to 2006, Wisconsin as a whole became wetter, with a 10 percent increase in annual precipitation (3.1 inches). The increase occurred primarily in southern and western Wisconsin, while northern Wisconsin experienced some drying (see figure 3). It is unclear whether these trends in precipitation are due to climate change or represent natural variation in rainfall over Wisconsin.

As with temperature trends, differences were significant from season to season (figure 12).

Winter: A modest increase in wintertime precipitation of 0.5 inch occurred from 1950 to 2006 in Wisconsin, an increase of about 14 percent.

Spring: Springtime precipitation also increased by half an inch on average during recent decades, an increase of about 6 percent. The most distinct increases, on the order of 1-2 inches, were seen over southern and western Wisconsin.

Summer: From 1950 to 2006, summertime precipitation decreased by 2-4 inches across northern Wisconsin and increased by 2-3 inches across southern and central Wisconsin. Summer precipitation for Wisconsin as a whole changed very little, increasing only 0.3 inch (a 2 percent increase).

Autumn: Most of the increase in precipitation across Wisconsin during 1950 to 2006 occurred in the fall. The state averaged an additional 1.8 inches, a 21 percent increase, with northwestern counties averaging increases of 2.5 to 3.5 inches in the fall.

Intense precipitation events: Both the frequency and magnitude of heavy rainfall event events have been increasing in Wisconsin. Madison, for example, has experienced a large number of intense precipitation events in the past decade: 24 days of two inches or more rainfall (compared with the previous maximum of 12 per decade since the 1950s) and nine days per decade of three inches or more rainfall (nearly as many as the five previous decades combined).

Photo: Avery Dorland

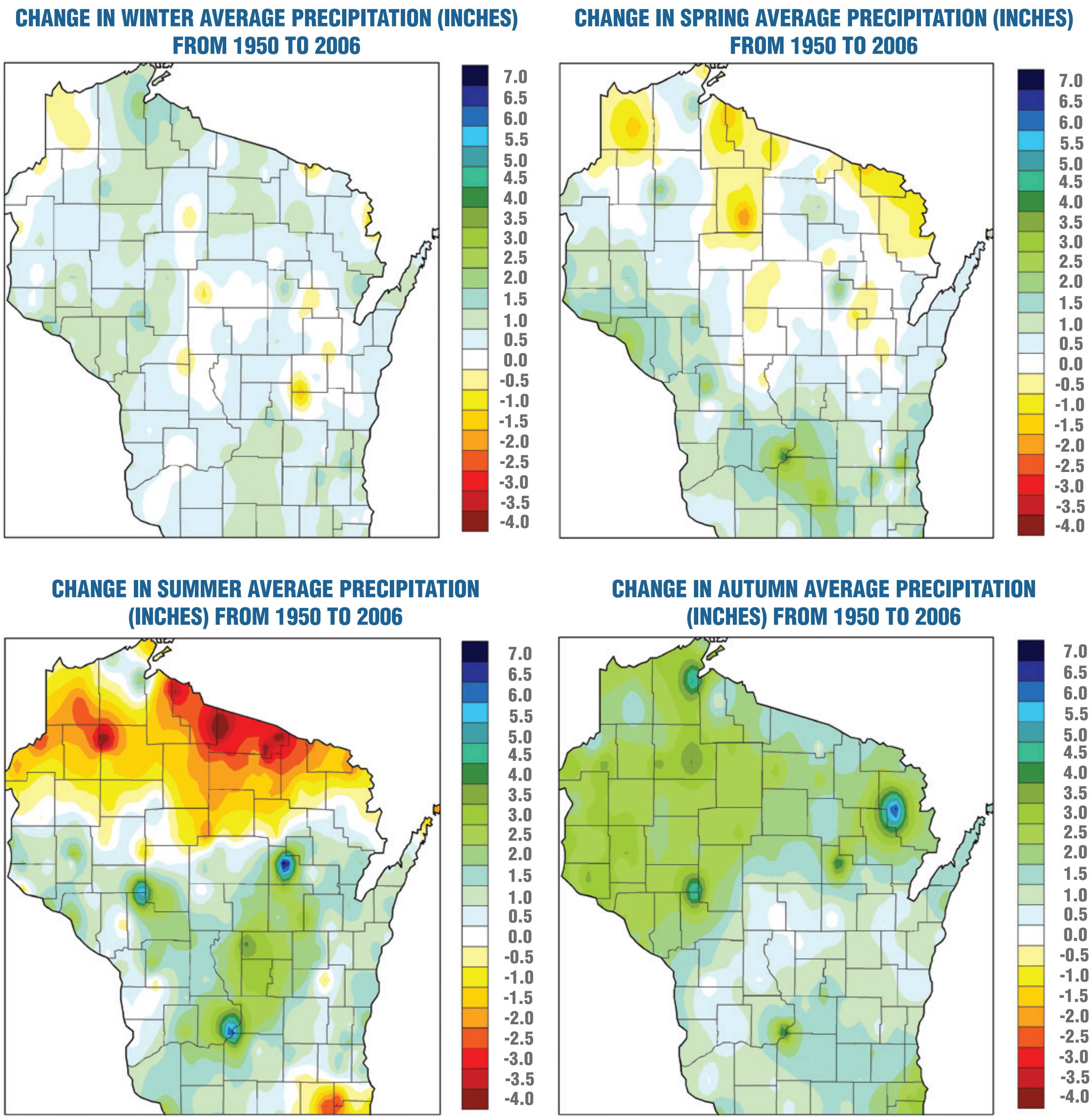


Figure 12. Precipitation generally increased across Wisconsin between 1950 and 2006, though the north saw a drying trend in spring and especially summer.

Source: Kucharik et al., 2006.

Projected Changes in Precipitation

Projections of precipitation are less certain than projections of temperature, with considerable disagreement among climate models. However, WICCI climate scientists say the models do indicate a 75 percent probability that annual average precipitation will increase. When broken down by season, a more interesting picture emerges. The models are in considerable agreement that precipitation will increase during winter and that more of that precipitation is likely to fall as rain rather than snow due to the rise in winter temperatures. The models also allow a fair level of confidence that spring and fall precipitation will increase, and total rainfall and intense rainfall events are projected to increase significantly during the winter and spring months from December to April. However, climate models do not agree on how precipitation patterns are likely to change in the summers ahead.

> WICCI climate scientists say the models do indicate a 75 percent probability that annual average precipitation will increase.

PROJECTED CHANGE IN WINTER AVERAGE PRECIPITATION (INCHES) FROM 1980 TO 2055

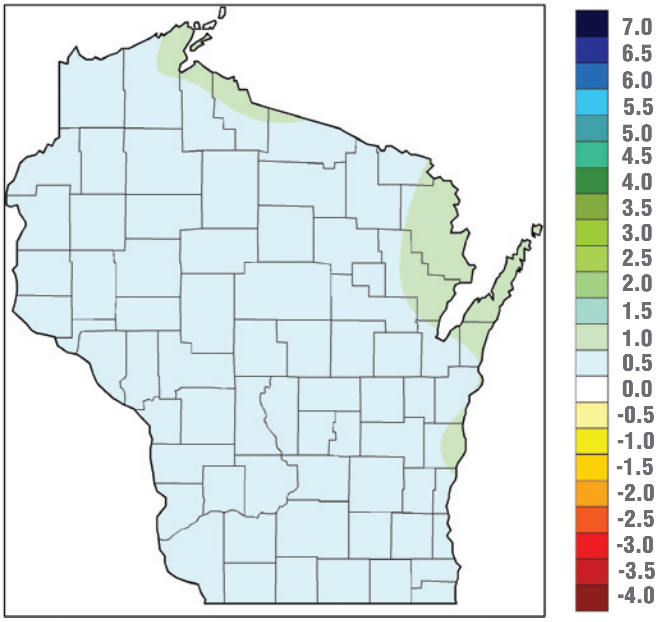
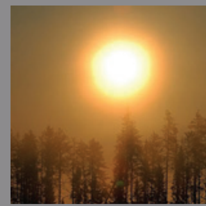
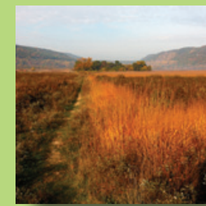


Figure 13. Winter precipitation is projected to increase by about 25 percent over most of Wisconsin by mid-century.

Winter: Wintertime precipitation is projected to increase by 0.1 to 1.2 inches by the mid-21st century, with the average of the climate models showing about a 25 percent increase over most of the state (figure 13). Statewide, the amount of precipitation that falls as rain rather than snow during the winter is also projected to increase significantly, and freezing rain is more likely to occur. As a result, snowfall, snow depth and the extent of snow cover across the state are all expected to decrease significantly by mid-century (figure 14).

Spring: Model projections show Wisconsin receiving more precipitation and more frequent intense events, especially during early spring. As in winter, early spring precipitation will be more likely to fall as rain than as snow. For example, the monthly precipitation as rainfall for March is projected to increase from 1.01 to 1.83 inches by the 2046-2065 time period, which represents a 50 percent increase in the amount of precipitation falling as rain rather than snow during that month.



Summer: Summertime precipitation projections are the least certain, with little agreement among climate models. This uncertainty creates challenges for predicting impacts from precipitation (or the lack thereof) during summer.

Autumn: Fall precipitation is projected to increase slightly by mid-century, somewhat more in the northern half of the state than the southern half, with most of this small change taking place in November.

PROJECTED SNOW

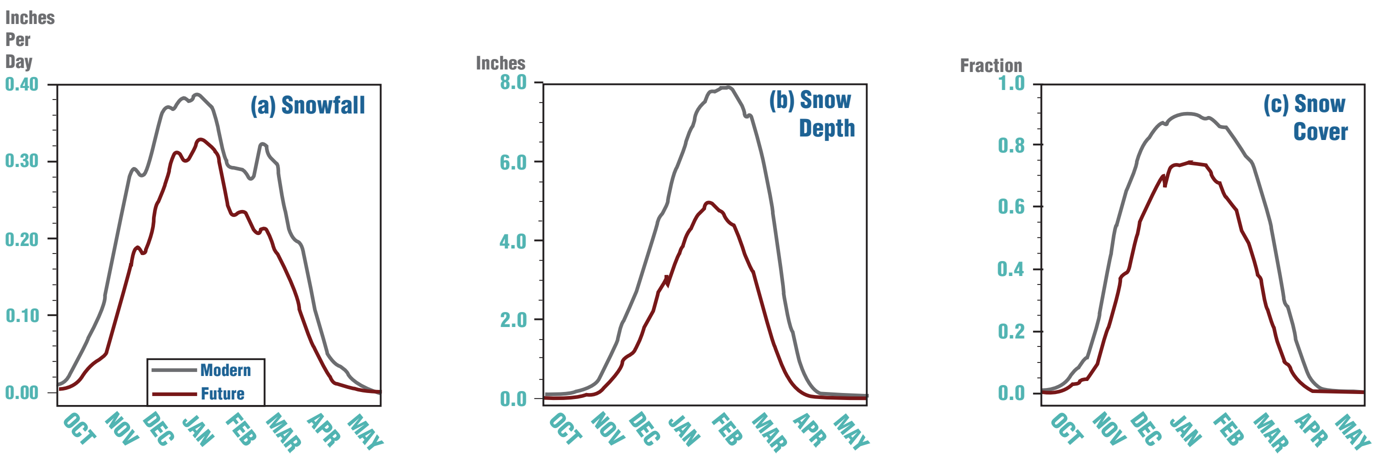


Figure 14. Projections of snowfall, snow depth and snow cover for Wisconsin for the mid-21st century show expected reductions as temperatures warm and more precipitation falls as rain rather than snow. The mean projection for the mid-21st century, when averaged across the state of Wisconsin, is a reduction in annual snowfall of 14 inches, or 29 percent. The greatest reductions in snowfall are likely on the flanks of the snow season, particularly in spring, resulting in a shortened snow season. For example, March snowfall may be reduced by at least three inches across the state. Due to both a reduction in the amount of snowfall and an increase in the rate of snowmelt, a dramatic reduction in snow depth is expected by the mid-21st century. In particular, snow depth may shrink by four inches in mid-March across Wisconsin, with decreases of 6-8 inches across northern counties. Snow projections for areas with lake-effect snow are less reliable due to limitations of the models.

Source: Notaro, M., D. Lorenz, D. Vimont, S. Vavrus, C. Kucharik, and K. Franz, 2010: 21st century Wisconsin snow projections based on an operational snow model driven by statistically downscaled climate data. International Journal of Climatology, DOI: 10.1002/joc.2179.

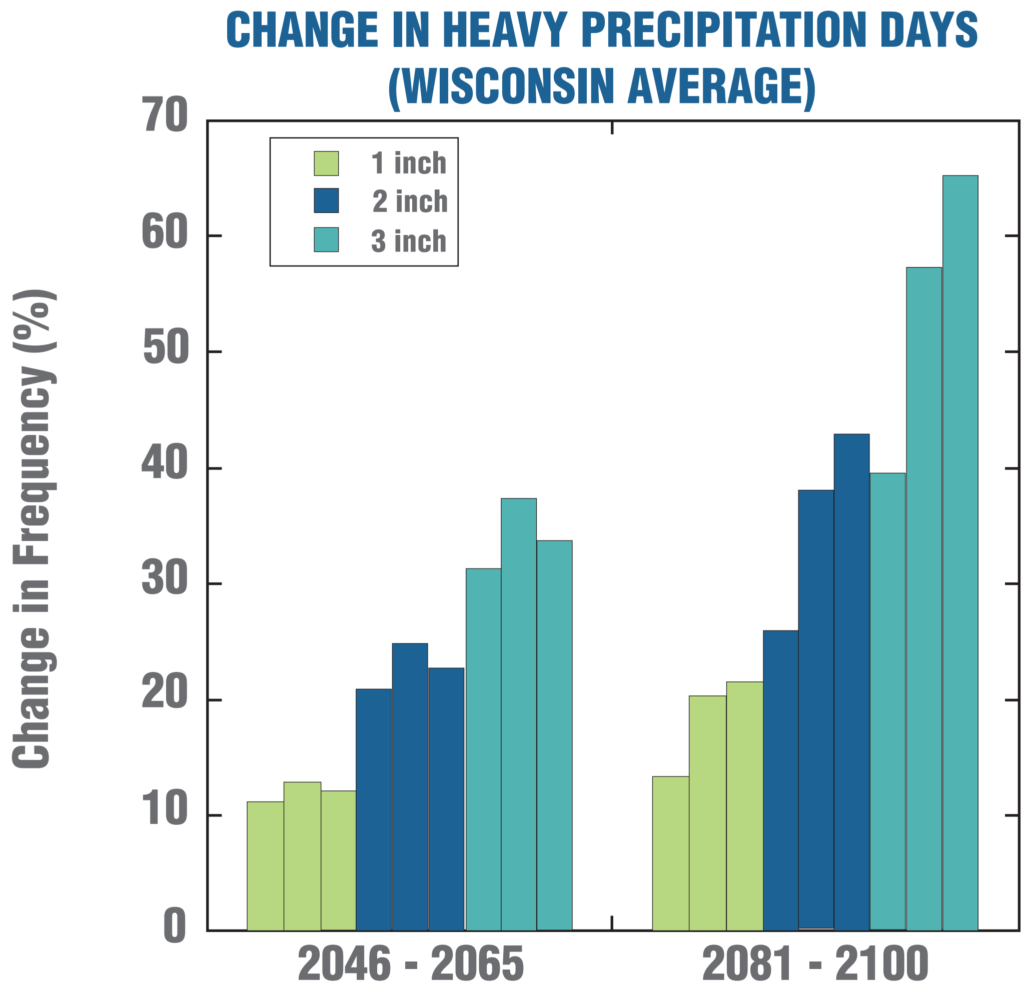


Figure 15. Intense rain events are more likely in the decades ahead. Each set of bars in each time period represents the expected increase in the frequency of intense rain events under the three greenhouse gas emission scenarios used by the Intergovernmental Panel on Climate Change. The colors represent daily rainfalls of at least one inch (green), two inches (blue), and three inches (teal). Within each trio of same-color bars, the left bar corresponds to the lower (B1) emission scenario, which assumes large reductions in emissions after the year 2050, the middle bar corresponds to the (A1B) scenario used as the basis for this report, and the right bar represents intense rain events under the higher (A2) carbon emissions.

Intense precipitation events: Typically, heavy rainfall events – at least two inches in a 24-hour period – are recorded at rain gauges roughly 12 times per decade in southern Wisconsin and seven times per decade in northern Wisconsin. By the mid-21st century, Wisconsin will likely have two or three more of these intense events per decade, about a 25 percent increase in their frequency (figure 15), with these changes concentrated in spring and fall. The heaviest rainfall events will also increase slightly in magnitude, according to the models. For example, averaged over the state, the magnitude of a 100-year storm event (five to seven inches of precipitation in a 24-hour period) is expected to increase by about 10 percent.

Drought: A change toward more heavy rainfall events but little change in total summertime rainfall implies more dry days in Wisconsin during the summer. More dry days, coupled with higher summer temperatures and increased evapotranspiration, can be associated with an increase in the likelihood of summer drought.

Evapotranspiration: Evapotranspiration – the amount of water that evaporates from land, water bodies and plants – is driven largely by temperature and solar radiation. An increase in temperature results in an increase in evapotranspiration; on the other hand, an increase in atmospheric moisture or cloud cover results in reduced sunlight hitting the Earth's surface and thus reduced evapotranspiration. Evapotranspiration is projected to increase across Wisconsin by mid-century, most notably in spring and fall, when a combination of higher temperatures and reduced cloud cover is projected by the climate models.

By the mid-21st century, Wisconsin will likely have two or three more intense rainfall events per decade, about a 25 percent increase in their frequency. The heaviest rainfall events will also increase slightly in magnitude.

For details on the methods used by the WICCI Climate Working Group, please visit www.wicci.wisc.edu, where the working group's full report is available.

Conclusion

Climate change is a reality for our planet and for Wisconsin. To better anticipate how climate change will affect Wisconsin, WICCI has undertaken a detailed study of recent historical trends in Wisconsin's climate. WICCI scientists have also developed projections of our state's future climates using some of the world's most advanced computer models. These studies reveal an emerging consensus on the range of possible climate changes that Wisconsin will experience. In particular, these studies find that Wisconsin is likely to become a much warmer state over the next few decades, with average temperatures more like those currently experienced in states hundreds of miles to our south. Our state is also likely to become somewhat wetter, with a modest increase in total precipitation and in the number of intense rainfall events. The amount of climate change varies by season, with winter experiencing the greatest warming and most likely increase in precipitation.

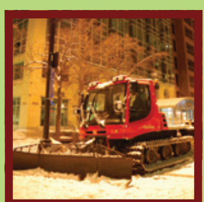
The WICCI climate analysis illuminates a growing need for more climate information in the years ahead. Wisconsin's climate monitoring network should be improved and maintained, and the Wisconsin State Climatology Office supported, to provide continued high-quality data to enable both short- and long-term climate impact modeling at a scale appropriate to support decision-makers in both the public and private sectors.

The next phase of WICCI climate research will include regional modeling that better incorporates the effects of the Great Lakes and more detailed analysis of evapotranspiration, net water balance and other climate factors.

CHAPTER TWO

UNDERSTAN

Frameworks for Understanding



WICCI and Adaptation

Photo: Courtesy of David Nevala and Climate Wisconsin

DING ADAPTATION

Climate adaptation is nothing new – rather, it is an ongoing process in human society and in the natural world. Adaptation is a matter of adjusting to our natural and built environments as they change, with the goal of thriving in our habitats and communities. For example, people migrate to areas with suitable climate or plant specific crops for which the growing conditions are well-suited. Plants and animals adapt to changes in their habitat conditions, as well. Sometimes adaptation is driven by threats, and other times opportunity drives adaptation.

Earth's climate is changing, and myriad physical and biological responses to this change are manifest in our landscapes, oceans and atmosphere. These responses to and effects of climate change have an impact upon our natural and human environments in a variety of ways.

Climate change is a complex phenomenon. The cause-and-effect relationships of climate change and its impacts do not necessarily fall like dominoes in a predictable linear pattern; rather, each climate change impact creates more of a ripple effect. Picture one component of climate change – rising temperatures, for example – as a pebble tossed into a pond. Watch the ripples spread outwards in concentric circles, affecting a greater area than the point of impact. Now imagine a handful of pebbles – heavier rains, less lake ice, reduced soil moisture – and watch the circles spread, intersect and overlap.

Because climate impacts play out differently from place to place and over time, and because human and ecological systems adapt at multiple scales of time and place – sometimes simultaneously – conflict is inherent in the process of forming adaptation strategies. Some may gain and some may lose as our climate changes, and there will be cases that require us to make value decisions while making management and policy decisions.

Adaptation is a matter of adjusting to our natural and built environments as they change, with the goal of thriving in our habitats and communities.

Because climate impacts play out differently from place to place and over time, and because human and ecological systems adapt at multiple scales of time and place – sometimes simultaneously – conflict is inherent in the process of forming adaptation strategies.

Frameworks for Understanding

An appropriate framework within which to discuss climate change adaptation is that of risk management, where decision-makers weigh the likelihood of an event against the consequences that could result from that event. The impacts identified throughout this report are likely to occur with a given probability, and if they do happen, they will result in either harms or benefits. Managers and policy-makers must rely on the probabilities of the impacts occurring as well as the degree of harm or benefit that is expected to result when making decisions about how and when to adapt to specific climate impacts.

Photo: Avery Dorland

Building societal and environmental resilience is a way of reducing risk and an overarching adaptation strategy to respond to climate change. Stakeholders can increase resilience either by creating a distinct process to address climate impacts or by "mainstreaming," a process in which climate is incorporated into other related decisions and topics. For example, existing programs and policies in community planning or urban design can be reviewed in light of climate change. Those current programs and policies can then be given adequate priority and implemented with the intent of building environmental resilience.

The framework of risk management can provide guidance to managers and decision-makers when confronting climate change, and it includes several principles of adaptation (discussed in more detail in Chapter 8: *Implementing Adaptation*) that can be relied upon. Here we highlight three principles that can help stakeholders determine where to get started and how and when to act: triage, the precautionary principle and "no regrets."

When managing natural systems, triage involves identifying resources, habitats or species where 1) the negative impacts are inevitable even with intensive intervention, 2) species will withstand climate impacts without the need for management, and 3) the success of adaptation will depend on the type

and amount of management. It would be most effective, then, to direct management efforts at that third group of resources, which might include a particular trout stream or stretch of coastline.

The precautionary principle addresses the reality that, sometimes, if we wait for certainty in predictions, it is too late to prevent a negative impact on an important resource, habitat, species or community. Human and natural communities have always adapted to changes in their environments, but the rate and scale of current and projected climate change necessitate that we be strategic in how we adapt – for instance, acting when the probability may be low but the risk is high. While we adaptively manage the impacts we currently experience from climate change, we must also anticipate impacts yet to come and adapt proactively. We can develop and implement adaptation strategies before the climate changes occur by taking a "better safe than sorry" approach in cases where the consequences of an event are known even though the details of the causes and effects are not yet fully understood.

"No regrets" strategies are management practices that both increase resilience in a changing climate and bring benefits regardless of climate projections. This involves reducing existing threats, building capacity in the public and private sectors, and expanding outreach and education on the impacts of climate change in Wisconsin. For example, climate change may prompt managers to implement practices that increase the resilience of a habitat – by protecting biodiversity and the integrity of the environment, both of which have value in the present. Thus there are "no regrets" in implementing or continuing these practices.

These three options are not the only approaches a risk management framework can provide; however, they

Photo: Avery Dorland

Photo: Darren Bush

Photo: Darren Bush

Photo: Darren Bush

Photo: Darren Bush

illustrate the value of thinking about climate change adaptation in terms of risk. Adaptation to climate change is a complex and difficult problem. By thinking in terms of risk, we can more easily grasp the scope of the problem and make it more manageable for individual decision-makers. For instance, although a triage approach will not address all aspects of climate change, it will help us focus on the most urgent and tractable aspects.

A number of tools, policies and practices are already in place in the field of natural resource management and community planning that will be valuable in reducing the negative impacts of climate change and taking advantage of any climate impacts that may benefit the state. It is imperative that managers and policy-makers evaluate the effectiveness of these options in light of expected climate change. We can leverage existing problem-solving systems by "mainstreaming" – a strategy in which we incorporate climate change issues into other decision-making processes. Mainstreaming is not about risk management but, rather, about efficient policy implementation. We are already working on problems related to the environment, and we cannot consider climate change in isolation from other issues.

RISK MANAGEMENT

Risk Characterization

Understanding how climate-related hazards could injure people, damage property, interrupt services, alter natural habitats or cause species loss is essential in developing strategies to reduce vulnerability by strategically targeting efforts to manage potential risk. The Federal Emergency Management Agency defines risk assessment for the built environment as "the process of measuring the potential loss of life, personal injury, economic injury, and property damage resulting from natural hazards by assessing the vulnerability of people, buildings, and infrastructure to natural hazards." And the U.S. Environmental Protection Agency defines ecological risk assessment as "the process for evaluating how likely it is that the environment may be impacted as a result of exposure to one or more environmental stressors such as chemicals, land use change, disease, invasive species and climate change."

Risk characterization identifies potential hazards to which a community, business, or institution is susceptible and estimates the potential consequences of these hazards to physical, social, and economic assets. Risk characterization also determines which areas are most vulnerable to damage from these hazards and quantifies the resulting cost of damages or costs avoided through future hazard mitigation. The potential impacts of flooding, heat waves, drought and other climate-related hazards in Wisconsin include:

- Public utility and service outages.
- Building losses and other property damage.
- Disrupted business operations.
- Human illness and disease.
- Agricultural crop losses from pests and diseases.
- Loss of biodiversity and ecosystem degradation.
- Polluted runoff damaging lakes and streams during storms.

Finally, risk characterization also analyzes the potential effectiveness of risk management, emergency response, and business continuity plans. These evaluations may identify needed insurance or financing to mitigate the financial impacts of climate-related losses.

Hazard Mitigation Planning

Hazard vulnerability assessments can play an important role in local land use planning and zoning processes. Community comprehensive plans, with hazard mitigation elements and effective land use policies, can reduce insured losses to property and avoid repeated losses to vulnerable properties and infrastructure. Legislative and executive bodies in state and local government can also examine their roles in creating incentives that decrease community vulnerability to climate-related hazards. As climate-related hazards and potential impacts increase in severity and become better understood, one might reasonably assume that efforts will be made to reduce risk and increase preparedness. Consequently, public sector fiscal constraints could lead to policy changes that curtail or substantially reduce government financial subsidies for development in areas at risk from natural hazards. Current federal subsidies include the National Flood Insurance Program, beach nourishment programs, tax benefits for second homes, and subsidies for infrastructure projects constructed in areas at risk from natural hazards.

WICCI and Adaptation

For the purpose of this report, WICCI relies upon the definition of adaptation put forth by the Intergovernmental Panel on Climate Change:

Adaptation is the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."

Adaptation can occur on a small or large scale. For example, individual people can adapt, or adaptation can take place at a regional or industry-wide level. Some strategies presented throughout this report can occur at a statewide level, and others are more appropriate for local communities or geographic areas to implement. Likewise, adaptation can happen at different time scales. Sometimes adaptation necessitates quick action, and other times circumstances such as the certainty of the science, the degree of urgency, and the cost or feasibility require us to plan decades in advance.

The goal of WICCI in producing this report is to identify the impacts of climate change in Wisconsin through vulnerability assessment and to inform the implementation of appropriate adaptation strategies. In the upcoming chapters of Section 2: *Impacts*, we describe the ways in which climate change is impacting and will likely continue to impact our natural and built environments throughout the state. In each chapter, we present adaptation strategies put forth by the contributing scientific working groups. In order to guide readers through the purposes of these strategies and illustrate their expected outcomes, we present them in four general categories:

Taking action to adapt to future climate**:** Strategies that have a clear present benefit, while creating resilience for adapting to the future, are preferred. This category includes natural systems management choices, social systems improvements and infrastructure modifications that provide both a climate adaptation benefit and present societal or ecosystem benefit. (Example: Increasing urban green space, thus reducing stormwater runoff while mitigating the heat island effect.)

Building capacity to make better decisions: A better understanding of climate science, impacts and adaptation strategies is needed along with tools for resource managers and other decision-makers. This category includes applied research, developing local modeling and management frameworks, implementing new management techniques at the local and program level, and training and education on using new tools for resource managers and others. (Example: Integrating climate adaptation strategies into local community planning activities such as stormwater management to prevent damaging runoff or flooding.)

Communicating with stakeholders: Education about the risks from future climate change and the need for polices and planning that will maintain society's flexibility for adapting to new and future impacts is fundamental to successful adaptation. This category includes communication with the public, decision-makers, community groups, local governments, nonprofits and others about impacts from climate change and the benefits of adaptation. (Example: Educating communities about the hazards of building in areas prone to flooding.)

While adaptation is not a substitute for mitigation, which aims to reduce the rate at which greenhouse gases enter the atmosphere, we do need to adapt to the climate change impacts we are facing today and devise adaptation strategies we can implement in anticipation of impacts we are likely to see in the future.

Filling gaps in our understanding: Our knowledge about how natural and human systems will respond to climate change is incomplete. This category includes scientific research, establishing long-term data-gathering programs, improving climate modeling and learning from climate adaptation efforts in other states. (Example: Creating a network of monitoring stations for rainfall and stream flows.)

Adaptation is the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."

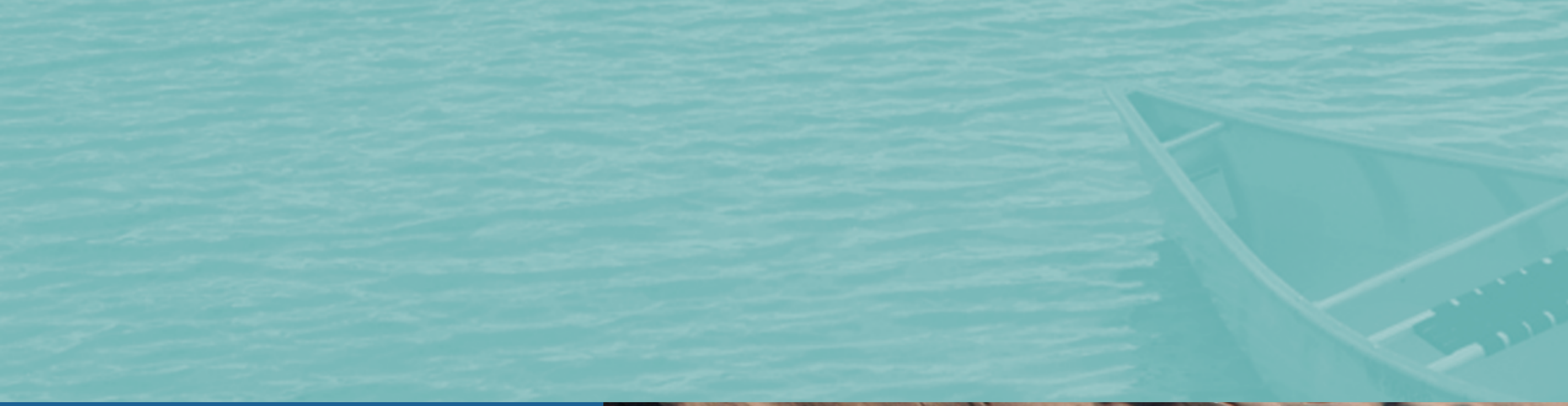
A more complete discussion of climate adaptation can be found in the WICCI Adaptation Working Group report, available online at www.wicci.wisc.edu.

Conclusion

The strategies proposed by the WICCI working groups in each of the upcoming chapters in Part 2: *Impacts* are not a prescription for successfully meeting the challenges of our changing climate. Rather, they represent the best ideas for adapting to the climate impacts upon Wisconsin's natural and built environments, developed with the climate knowledge available today. We expect that future work will improve upon and expand the range of these preliminary ideas.

Photo: Elizabeth Katt-Reinders

PART 2:
IMPACTS



Impacts and Vulnerabilities

Adaptation Strategies

Wisconsin boasts a wealth of water resources. The Mississippi River, Lake Superior and Lake Michigan help define our state borders, and the 84,000 miles of streams, 15,000 lakes, 5.3 million acres of wetlands and abundant groundwater nourish plants and animals, provide drinking water for urban and rural communities, support industry and agriculture, and enrich our recreational activities.

Wisconsin's climate is changing, and our water resources and aquatic ecosystems are changing, too. In this chapter, we will examine the ways in which climate change affects the quality and quantity of water resources, including inland lakes, rivers and streams, groundwater and wetlands. We will describe the physical responses within the water cycle to rising temperatures and shifting precipitation patterns, discuss the impacts of those changes, and present adaptation strategies where possible. (For discussion of impacts on the Great Lakes, see Chapter 6: *Coastal Resources* and Chapter 9: *Moving Forward*.)

Wisconsin's Water Resources

Wisconsin's waters respond to climate through a range of processes and, in some cases, serve as indicators of climate change. Historical records demonstrate that water resources are intimately linked to local and regional climate conditions. Long-term records of lake water levels, lake ice duration, groundwater levels, stream baseflow, and stream and river flooding have corresponding relationships with long-term trends in atmospheric temperature and precipitation.

Photo: Judith Kozminski

CHAPTER THREE

WATER RESOURCES

We anticipate that future climate projections will affect our state's water resources in both quantity and quality. The hydrological responses to climate change will vary, however, among different geographic regions of the state. This is clearly evident in Wisconsin's historical records as well as in the future climate projections produced from the WICCI downscaled climate data. The differences in hydrological responses reflect variations in land use, soil type and surface deposits, groundwater characteristics, and runoff and seepage responses to precipitation.

Climate Drivers

The two driving forces of climate change that will affect water resources are increased temperature and shifting precipitation patterns. Climate models forecast that Wisconsin's temperature will increase in all four seasons, with the greatest increase in winter. The models project precipitation increases in fall, winter and spring. The combination of warmer temperatures and changing precipitation patterns suggests that we will see a significant increase in the amount of winter precipitation falling as rain rather than snow and that freezing rain is more likely to occur. The magnitude and frequency of precipitation are also projected to increase in spring and fall.

These changes in temperature and precipitation will affect Wisconsin's water cycles, with major impacts on lakes, streams, groundwater and wetlands. Some of the physical responses we can expect to see include:

- Increased average surface water and groundwater temperatures.
- Shorter periods of ice cover on lakes and streams.
- Decreases in the thickness of lake ice cover.
- Increased evapotranspiration rates during the longer growing season.
- Increased number of freeze-thaw events.
- More groundwater recharge due to increases in winter and spring precipitation. (Groundwater recharge refers to water that infiltrates and moves downward into the saturated zone of an aquifer.)
- Changes in recharge and discharge based on whether precipitation falls as rain or snow. (Groundwater discharge refers to groundwater that reaches the surface, such as springs, seeps, lakes or rivers.)
- Increased number of high water events causing flooding.

Impacts and Vulnerabilities

To improve our understanding of how projected climate changes may affect Wisconsin's water resources, we consider future climate projections in the context of historical variability and hydrological trends of the past. When viewed together, a picture of climate change impacts on Wisconsin's waters emerges.

Hydrologic Processes

Hydrologic processes are the ways in which water moves through the water cycle (figure 1). When one part of the system is affected by the driving forces of a changing climate, all other parts are affected. Most of the water entering the landscape arrives as precipitation that falls directly on water bodies, runs off the land surface and enters streams, rivers, wetlands and downstream lakes or percolates through the soil, recharging groundwater that flows underground and re-emerges as springs into lakes, wetlands and streams.

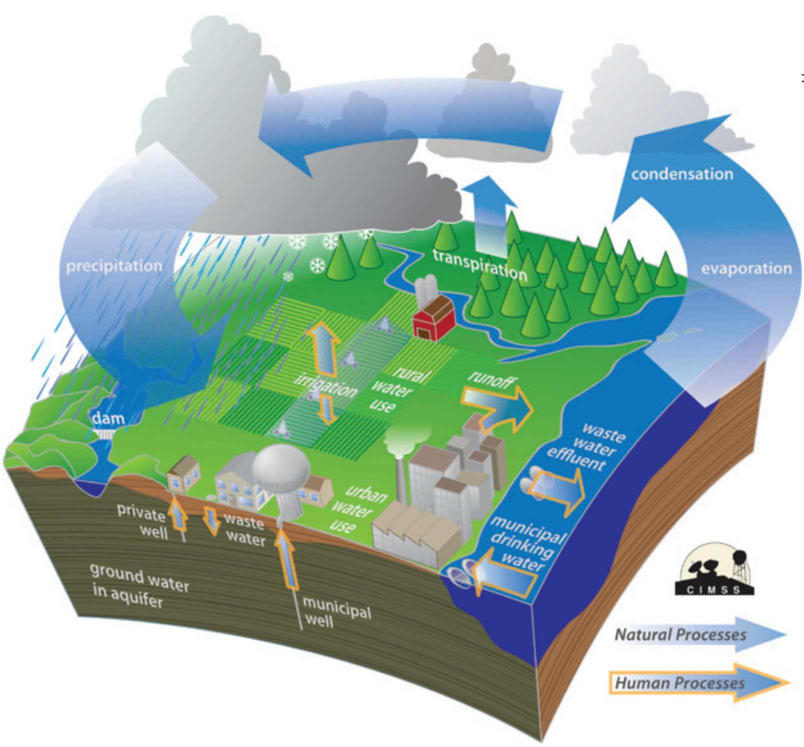


Figure 1. Climate change may alter how water moves through the water cycle.

Other important hydrological processes include evapotranspiration and sublimation.

We may not always be able to predict the systemwide, sometimes abrupt, changes in hydrologic patterns across the state. Examples include groundwater flooding, with groundwater tables rising as much as 30 feet in one season, leaving formerly dry ground inundated for periods of time; streams drying up due to lack of groundwater recharge and discharge to the streams; or changes in aquatic ecosystems, such as the increasingly long periods of time when blue-green algae blooms occur in nutrient-rich lakes.

Evaporation: *The process by which water is changed from a liquid into vapor.*

Sublimation: *Direct evaporation of snow and ice.*

Transpiration: *The process by which plants give off water vapor through their leaves.*

Spatially, the state will not be affected uniformly. For example, parts of the state have experienced increased precipitation while other parts have experienced drought. Differences in the physical characteristics of a place – such as variations in land use, soil type and surface deposits, groundwater characteristics, and runoff and seepage responses to precipitation – can confound the influence of climate change, leading to a wide range in system responses.

There are also thermal impacts as atmospheric and water temperatures rise. Aquatic ecosystems can suffer if streams or other resources are taxed further by heavy influxes of warm water, either from overland flow, such as water picking up heat along a parking lot, or stormwater discharged from a stormwater management facility.

THE CENTRAL SANDS

The Central Sands region of Wisconsin is of particular hydrological interest because of how much its water resources are linked to groundwater. The Central Sands covers parts of five Wisconsin counties, and the region is characterized by a thick mantle of sandy glacial materials, more than 100 feet thick in many places, that covers impermeable bedrock. These sandy materials compose a productive aquifer holding an important groundwater resource that feeds the area's extensive lakes, streams and wetlands.

Groundwater, which originates from precipitation that percolates through soils, is ultimately discharged to surface waters. Lakes and wetlands exist where groundwater levels intersect depressions in the landscape, and streams occur where groundwater discharges to channels. Thus, changes in the landscape's hydrologic budget that affect groundwater also affect surface water ecosystems.

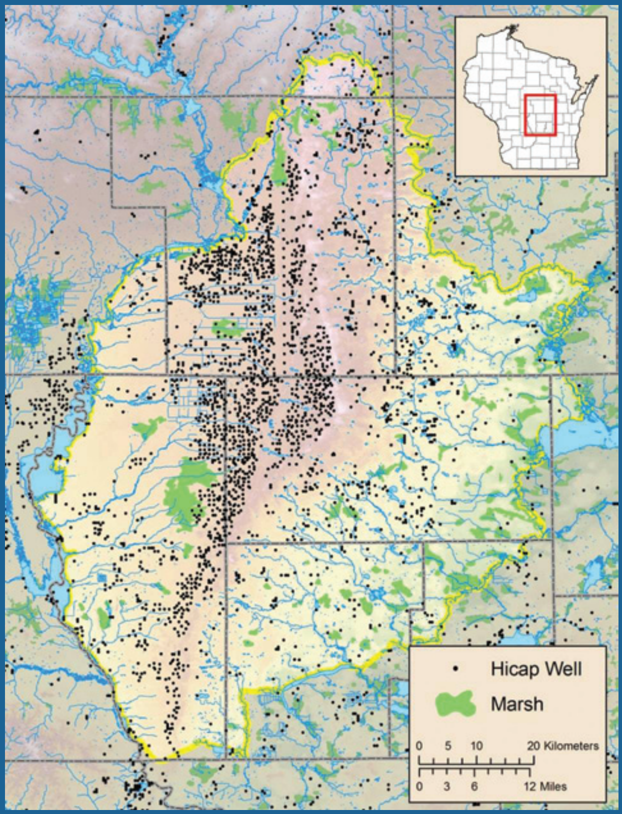


Figure 2. High-capacity wells in the Wisconsin Central Sands.

Source: WICCI Central Sands Hydrology Working Group.

Although climate change is expected to drive changes in the hydrology and water resources of any Wisconsin landscape, the Central Sands region is a distinct case because of its heavy dependence on irrigation for agriculture. Groundwater reserves are tapped by Wisconsin's highest concentration of high-capacity wells, with the greatest amount of groundwater pumping in the state used chiefly for agriculture. Irrigated land has been increasing in the Central Sands region for about 50 years and currently covers about 175,000 acres. The potential effects of irrigation have been explored in classic studies in the 1960s and 1970s as well as in more recent works. These studies suggest that irrigation can reduce net groundwater recharge by 20-25 percent compared with non-irrigated lands. In fact, the region has already experienced serious groundwater pumping impacts on lakes, streams and wetlands. This reduction has been sufficient to dry up some lakes and streams in the region under only moderate drought conditions. (Please see the Plover River case study in the Water Resources Working Group Report at www.wicci.wisc.edu).

Nutrient-Rich: Containing high concentrations of compounds of nitrogen, phosphorus and potassium that promote plant growth.

Lakes

Climate change will impact lakes in several ways. Some of the most significant impacts include greater sediment and nutrient loads washing into lakes from increased stormwater runoff, decreases in ice cover throughout the state, physical impacts on lakes, changes in lake levels and changes in the composition of aquatic species communities.

Increased Sediment and Nutrient Loading

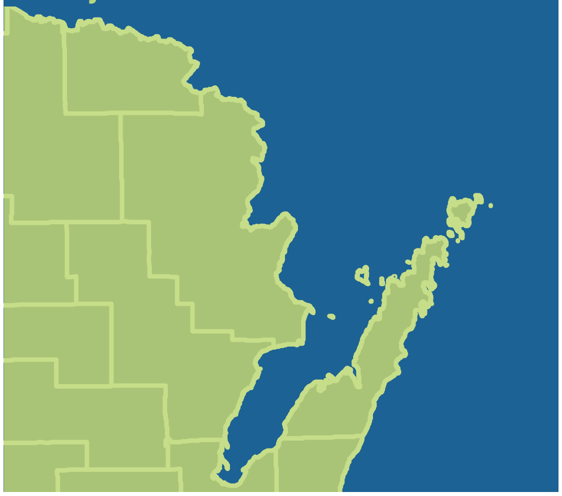
Polluted runoff is the biggest cause of water pollution in Wisconsin. It results when large precipitation events wash sediment and nutrients off the landscape, threatening downstream surface water resources. When runoff containing nutrients such as phosphorus washes into water bodies, the result is excess nutrient loading. These nutrients fertilize algae and boost their growth.

Sediment from runoff along with algae makes waters murky and turbid, decreasing visibility for sight-feeding fish and diving birds. It also limits photosynthesis, making it difficult for submerged aquatic vegetation to grow. These underwater plants are essential for a balanced and productive aquatic insect and fish community, so increased amounts of sediment and nutrients impact every facet of aquatic habitats.

An increase in the size and frequency of heavy rainfall events and a shift to more rainfall in winter and spring will increase runoff from surrounding land when plant cover is reduced or absent, which means sediment and nutrient loading to lakes will also increase. The degree of sediment and nutrient loading across the state depends on land use, soils and geology. Most of the loading comes from a relatively small portion of the landscape, so soil conservation practices in those regions have a large effect on the degree of

THE PROBLEM WITH PHOSPHORUS

Lake Michigan's Green Bay is one of Wisconsin's water bodies being affected by excess nutrient and sediment loading. Sediment enters Green Bay mainly from the Fox River and its tributary streams. A nutrient of particular concern for Green Bay water quality is phosphorus. Phosphorus stimulates algae growth, and algal blooms contribute to the problem of reduced light penetration and lower oxygen concentrations in the water column. Blue-green algae are actually photosynthetic bacteria that can become a serious concern under high phosphorus conditions. These prolific microorganisms produce toxins of health concern to humans and wildlife, and they outcompete the more desirable species of microscopic algae that form the base of the aquatic food chain. If phosphorus concentrations increase and boost blue-green algae growth, food chain efficiency will be reduced and this could lead to an unbalanced fish community that favors invasive bottom-feeding carp to the detriment of native fish species like walleye. Currently, the likelihood of increased phosphorus concentrations from an increase in runoff is one of the greatest threats to the Green Bay aquatic ecosystem.



soil loss and subsequent sediment and nutrient loading throughout the watershed. (See Chapter 3: *Agriculture and the Soil Resource* for more on soil conservation practices.) In fact, scientists estimate that if we target soil conservation practices in the 10 percent of Wisconsin watersheds that lose the most sediment to runoff, we could reduce statewide sediment loading by 20 percent. Current soil conservation practices, which assume a certain tolerable level of soil loss, are insufficient to meet water quality standards. As our climate changes, meeting these standards will be even more challenging.

The seasonal timing of increased precipitation will play a critical role in the potential impacts on our lake resources. If the ground is frozen but precipitation falls in the form of rain, it will run off into surface waters

Scientists estimate that if we target soil conservation practices in the 10 percent of Wisconsin watersheds that lose the most sediment to runoff, we could reduce statewide sediment loading by 20 percent.

PRECIPITATION AND NUTRIENT LOADING

Data analysis of Dane County's Lake Mendota from 1980 to 2007 highlights the significance of precipitation and runoff for nutrient loading to lakes. The lowest concentration of total phosphorus in the lake was in 1988 as a result of a two-year drought. There was a reduction in the amount of polluted runoff entering the lake, and water clarity was at its best. In contrast, in 1993, total phosphorus concentrations were highest following very high-runoff spring and summer events. If Wisconsin's changing climate includes an increase in precipitation or heavy rainfall events such as those that occurred during the most recent decade (2000-2009) in Madison, these changes will lead to increased nutrient loading to lakes. This points to the need for best management practices to reduce sediment and nutrient loading.

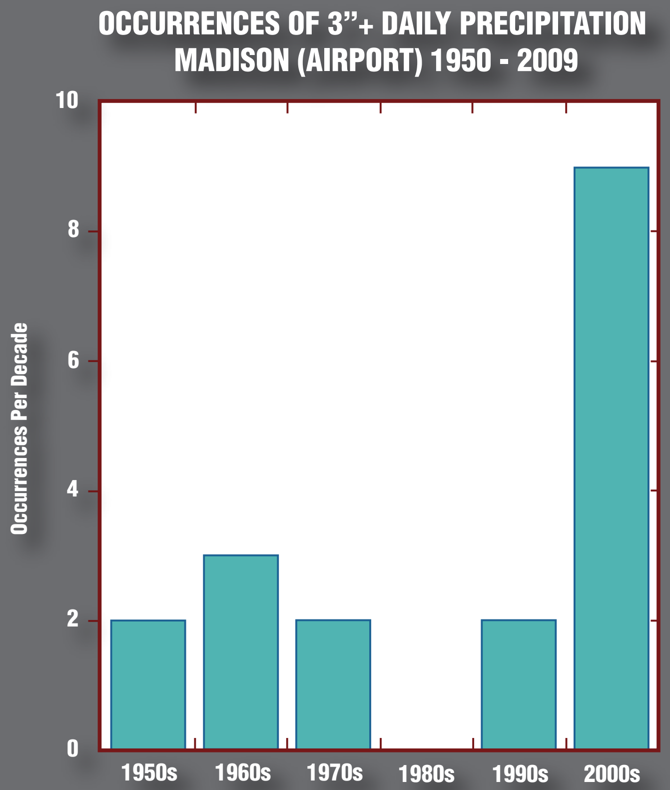


Figure 3. Precipitation trends recorded in Madison.

Source: Updated from Steve Vavrus, Nelson Institute Center for Climatic Research, University of Wisconsin-Madison.

and carry contaminants with it, particularly phosphorus and nitrogen from soil and manure. In contrast, when the ground is not frozen, precipitation is more likely to infiltrate the ground and recharge groundwater.

Changes in Ice Cover

Climate models predict that with rising temperatures in fall, winter and spring, ice cover will decrease in duration throughout the state. In the future many of Wisconsin's lakes, particularly in the southern part of the state, may even be ice-free all winter. Variability in the ice cover of lakes is quite sensitive to changes in weather and climate. Decreases in the duration of ice cover in lakes throughout Wisconsin have resulted from a combination of freeze dates coming later, indicative of warmer fall air temperatures, and ice breakup dates coming earlier, indicating warmer winter and spring air temperatures.

Ice cover records from throughout the Northern Hemisphere have been used to demonstrate long-term climate changes that have occurred over the past 150 years. They also reflect short-term climate variability. Scientists can graph historical ice cover records and weather-climate patterns and distinguish short-term effects from long-term changes.

In shallow lakes during the winter, sunlight cannot penetrate heavy ice cover that is shrouded in snow for a long period of time. Consequently, oxygen is depleted by decomposing algae and other organic material, and many fish can die from asphyxiation in a process called "winterkill." Shorter periods of ice cover because of warmer winter temperatures would reduce these winter fish kills in shallow lakes.

In summer, deeper inland lakes could face increasing challenges of depleted oxygen levels in the bottom waters where coldwater fish such as lake trout and cisco live. Under normal circumstances, seasonal changes in temperature trigger a fall mixing of the thermal layers of a lake after a period when colder bottom waters are relatively isolated from the warmer surface waters – a process called thermal stratification. This fall mixing redistributes oxygen to the deeper waters of the lake where the oxygen has been depleted over time, especially in cases where lakes have become more fertile with more organic matter for bacterial decomposition.

Prolonged periods of warm weather due to either early spring warming or warmer fall temperatures – or both – would lengthen the period of thermal stratification and allow for more oxygen depletion throughout the entire zone of bottom waters. As a result, coldwater fish would no longer find oxygenated waters in their required temperature ranges because the oxygenated surface waters would be too warm for them.

LAKE ICE

The long records from these lakes make it clear that ice cover is declining even in the face of great variability over years and decades. Note that the unusually long or short ice covers in individual years are not a change in climate but yearly variations in weather affecting ice formation and decay. For example, a detailed examination of the ice records for Lake Mendota shows that the total duration of ice cover has declined at a rate of about 1.9 days per decade, or 19 days per century. The shortest ice cover period for the lake was 21 days in the winter of 2001-02. This is in contrast to the average ice cover period of about 100 days over a 154-year long record. The change in ice cover can also be seen in the occurrence of extreme years. The winters with the 10 longest periods of ice cover all occurred before 1900, while the winters with the 10 shortest periods of ice cover occurred mostly in recent years.

TRENDING TOWARD SHORTER DURATION

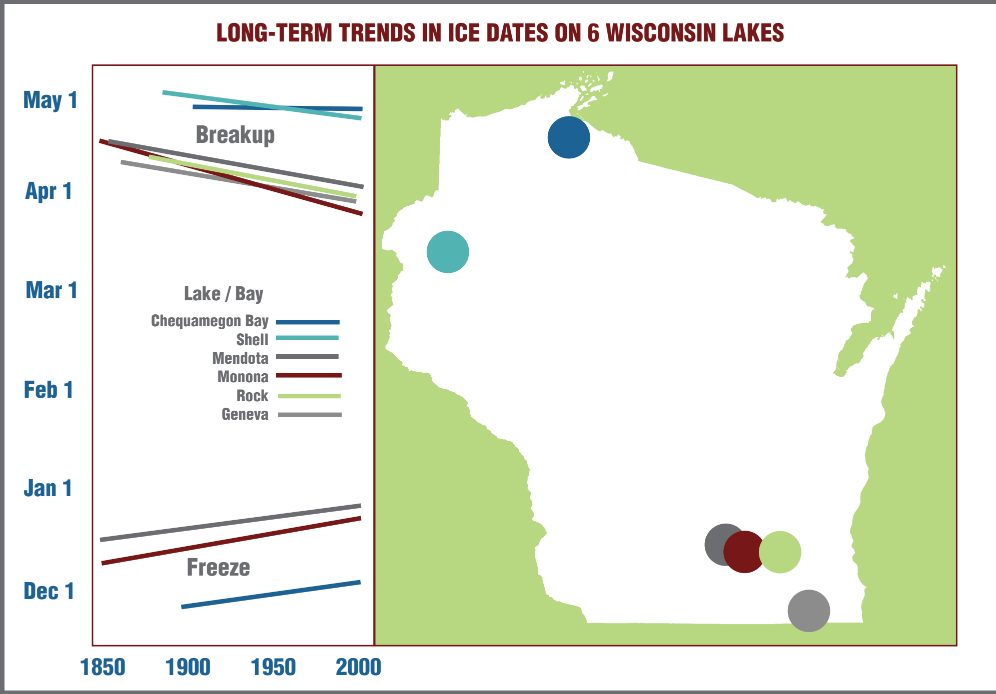


Figure 4. This illustration shows that over the past 150 years ice cover occurs later and breaks up earlier. The circles indicate the location of the lakes and the colors key to the trends.

Source: Magnuson, J.J., J.T. Krohelski, K.E. Kunkel, and D.M. Robertson. 2003. Wisconsin's waters and climate: Historical changes and possible futures. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 90: 23-36.

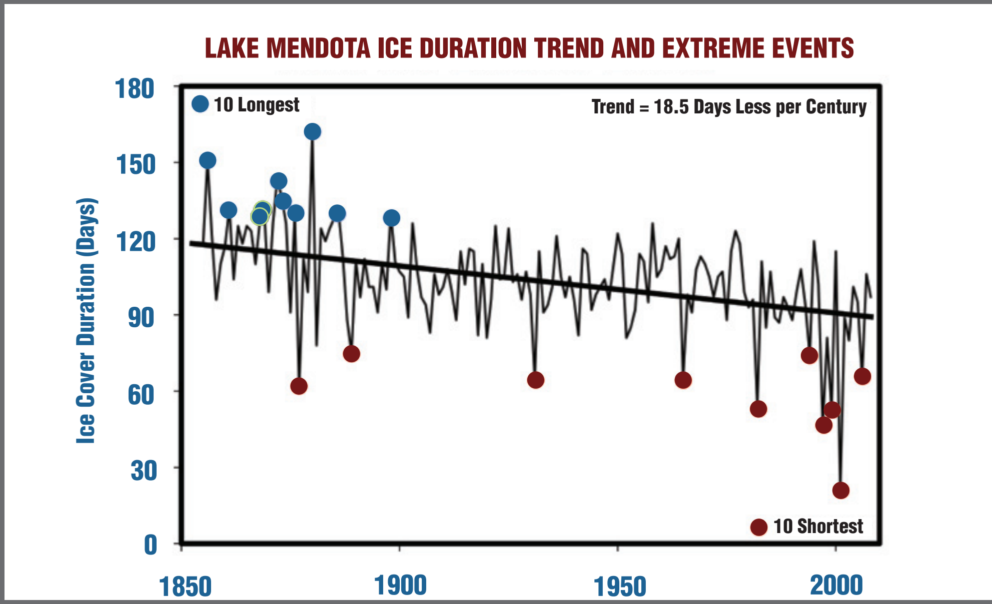


Figure 5. Ice duration of Lake Mendota. The straight line indicates an overall decrease of 19 days per century in ice cover during the 154-year period of record. The winters with the 10 longest periods of ice cover are identified with blue circles and the 10 shortest periods of ice cover are identified with red circles.

Source: John J. Magnuson, Center for Limnology, University of Wisconsin-Madison.

The loss of coldwater fishes such as cisco or lake trout would be a negative impact on biodiversity. The decline in winterkill would allow game fishes like northern pike to become established, which could increase fishing opportunities; however, a diverse community of small fishes intolerant of pike predation could become less common in Wisconsin.

Recreational opportunities will also shift as a result of changes in ice cover on lakes and streams. An increase in the ice-free period may increase recreational opportunities for boating, fishing and swimming; however, winter recreational opportunities like skiing, snowmobiling and ice fishing would decline.

Physical Impacts

Climate change makes lakes susceptible to increases in a host of physical impacts. With ice cover on the lakes for less time, the longer period of open water increases the impact of wave action on the shoreline. Heavy rainfall events are another factor. Climate scientists predict an increase in the magnitude and frequency of heavy downpours, and these events can cause shoreline flooding and erosion, increase property damage and cause dam failures. In some cases, intense rainfall events redefine the boundaries traditionally considered the limits of a lake's shoreline as waters spread beyond historical boundaries.

A recent example that illustrates the physical impacts of heavy rainfall events on lakes is the 17 inches of rain that fell in southern Wisconsin in June 2008. During this 10-day period of rainfall that was capped by one intense event, the water in Lake Delton breached a portion of the lakeshore, washing out a road and homes. The lake drained completely into the Wisconsin River, resulting in millions of dollars in damage.

CASE STUDY: THE STORMS OF 2008

Heavy rainfall across parts of southern Wisconsin during June 2008 overwhelmed stormwater management infrastructure, causing widespread flooding. Intense rainstorms have varied widely in the past but have increased in number in recent years and are forecast to become more frequent in a warming climate. Such storms led to a massive increase in nutrient and sediment loading to surface waters caused by erosion, and:

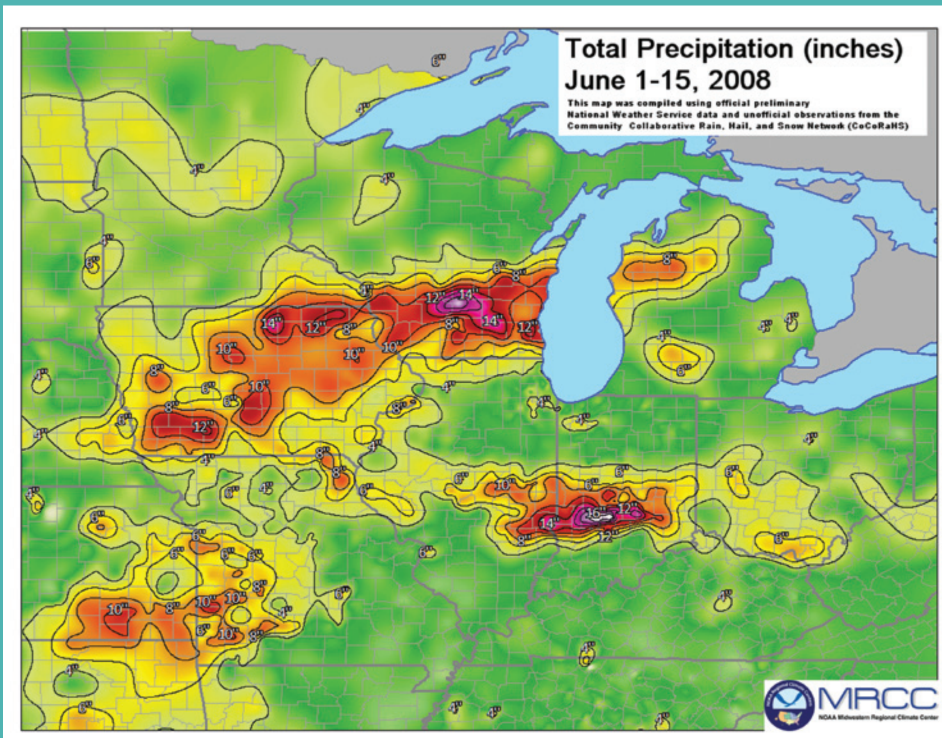


Figure 6. 2008 Spring Flooding Radar Map

- **Stage readings on 38 river gauges broke previous records.**
- **810 square miles of land was flooded.**
- **28 percent of the 2,500 private wells tested were contaminated.**
- **90 million gallons of raw sewage overflowed from 161 wastewater treatment plants.**
- **The Federal Emergency Management Agency paid a total of $34 million in flood damage claims.**

Changing Lake Levels

Lake water-level fluctuations are important to lake and water managers, lakeshore property owners, developers and those using the lakes for recreation. Lake levels change from year to year, and extreme high or low levels can present problems by restricting access to water, hampering navigation, flooding lakeshore property, damaging shorelines and structures, and changing near-shore vegetation. We focus in this section on changing levels in inland lakes, and the effects of changing water levels in Lake Michigan and Lake Superior are discussed in Chapter 6: *Coastal Resources*.

Lake levels may change as a result of climate change, but these changes may not be the same throughout the state. In addition, the net balance between precipitation and evaporation remains difficult to predict with high confidence. Because of this, lake levels may go up or down dramatically based on the geographic location of a lake and local rainfall patterns. If more evapotranspiration than precipitation and groundwater recharge occurs in an area, lake levels will drop. Lake levels will rise if precipitation, recharge or increased runoff to urban lake systems is greater. In addition, regional differences in soil type and land cover will affect how climatic changes translate into hydrologic changes.

Photo: John J. Magnuson

Lake Mendota ice breakup, Spring 2010.

CASE STUDY: SILVER LAKE IN BARRON COUNTY

Changes in lake levels, both up or down, will have impacts on aquatic habitats. A study of Silver Lake in Barron County found that during periods of low water, the lake has low levels of nutrients, low algal growth and very good water clarity. During periods of high water, the lake becomes eutrophic and has excessive nutrients, higher algal growth and poor water quality. Silver Lake is in a relatively pristine area of Wisconsin where phosphorus concentrations in surface water runoff are relatively low and where phosphorus loading would most likely be diluted. Changes in land use that result in increased phosphorus concentration in stormwater runoff will likely exacerbate the effects of increases in precipitation from climate change.

Water levels of lakes and shallow groundwater tables integrate the effects of hydrologic processes within a given landscape. Therefore, changes in the water levels of lakes and groundwater can be the result of natural climatic phenomena or other changes in their watersheds, such as changes in land use. Based on results from climate model projections, it is likely that future climate change will either cause changes in hydrologic budgets, such as increases or decreases in water levels or flows, or cause water levels to fluctuate more widely in response to larger fluctuations in precipitation and runoff.

Seepage lakes, those with no outlet and for which most water input comes from precipitation and groundwater, are more sensitive to changes in precipitation and groundwater elevations than drainage lakes, which have stream inlets and outlets. Water in many seepage lakes in northern Wisconsin is at its lowest levels in 60 years (see Anvil Lake sidebar). In the southern part of the state, water levels in most seepage lakes have

ANVIL LAKE

Anvil Lake (Vilas County), a northern Wisconsin seepage lake for which water-level records have been kept for 74 years, demonstrates pronounced, recurring highs and lows. The data appear to indicate that lake levels are getting progressively lower during each succeeding dry period and especially during the present period for this lake. In the future, water loss through evapotranspiration associated with warmer temperatures would exacerbate any drought effect if increases in evapotransporation exceed increases in precipitation, as future climate scenarios suggest. Other lakes and wetland systems that are at higher elevations in landscapes where water levels depend on local groundwater inputs and direct precipitation countered by evaporation are expected to be subject to this same phenomenon.

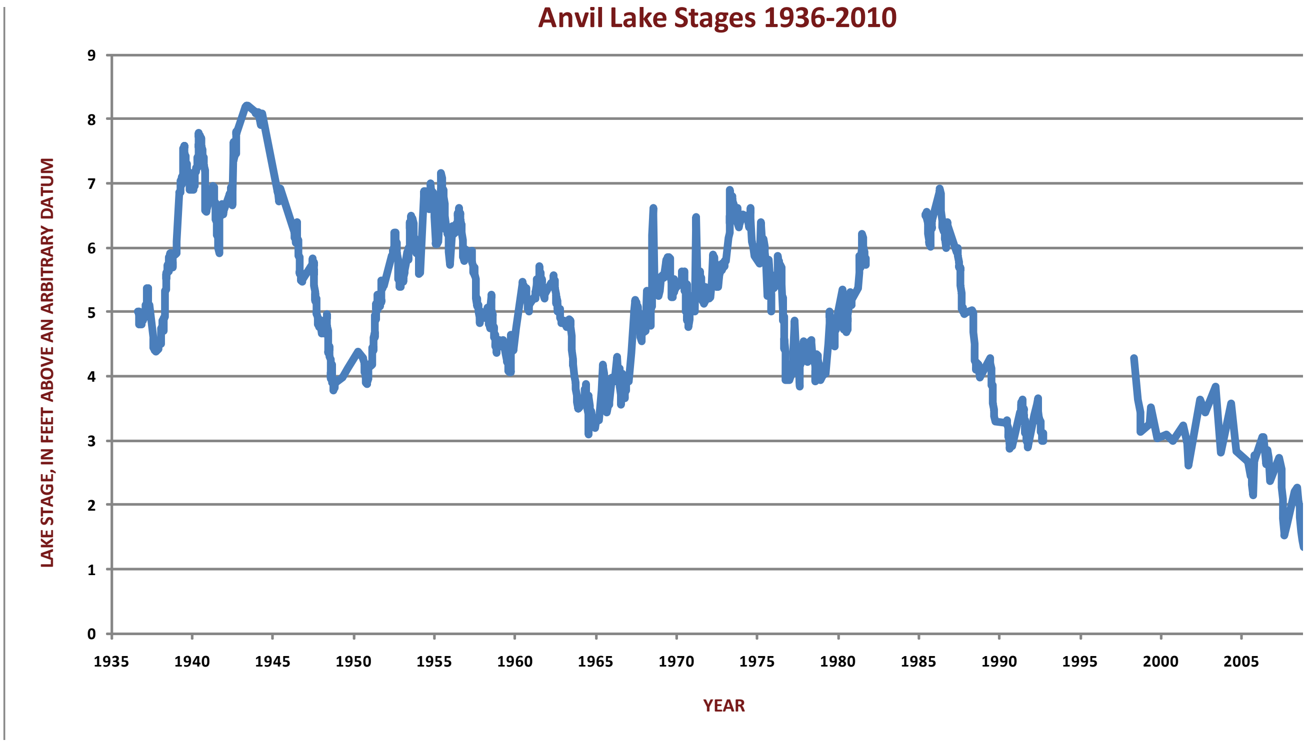


Figure 7. The water levels of Anvil Lake are characterized by recurring droughts. The levels reached between 2004 and 2010 are the lowest observed to date and are associated with the reduced precipitation in Northeastern Wisconsin in recent years.

increased. This increase is believed to be partly caused by changes in the amounts and timing of precipitation and by watershed land use changes.

For all but the smallest lakes, flooding generally results from unusually high amounts of rainfall over weeks to months. As with stream and river flooding, increases in winter and spring rainfall are likely to have the greatest affect on lake flooding. As mentioned earlier, this can be complicated by the role of frost and frozen ground, which can either increase or decrease runoff and recharge. Slow-draining lakes and seepage lakes without natural outlets will be most vulnerable.

Change in Species Composition

Climate change will affect the composition of aquatic species living in lakes, including invasive species. Floods and droughts alter the physical conditions of a lake, affecting the suitability for plant and animal species and in some cases making them better suited for invasive species. Unusual floods can connect water bodies and allow invasive species to enter waters that had typically been confined or isolated. Rising temperatures affect thermal thresholds of plant and animal species, and polluted runoff from increased precipitation or heavy storms affects many facets of aquatic ecosystems, such as algal communities.

Increased temperatures may lead to introductions and survival of aquatic invasive species not previously recorded in Wisconsin. Species not native to the area may be more likely to survive when temperatures rise because many species, such as *hydrilla*, water hyacinth or red swamp crayfish, will be able to overwinter. These species are native or well-established in the southern U.S. but thought to be limited by cold temperatures and ice cover; however, two recent findings of these species in small constructed ponds in Wisconsin have shown that overwintering is possible and will become even more likely with reduced or no ice cover. An example of a southern native fish species that could further invade due to warmer temperatures is the gizzard shad, a problem species in reservoirs in Ohio and other areas south of Wisconsin.

Please refer to Chapter 4: *Natural Habitats and Biodiversity* for more detail on climate change impacts on lakes and other aquatic habitats.

Drainage lakes: *Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems but generally have shorter water residence times than seepage lakes. Watershed protection is usually needed to manage lake water quality.*

Seepage lakes: *Lakes without a significant inlet or outlet, fed by rainfall and groundwater. Seepage lakes lose water through evaporation and groundwater moving on a downgradient. Lakes with little groundwater inflow tend to be naturally acidic and most susceptible to the effects of acid rain. Seepage lakes often have long water residence times, and lake levels fluctuate with local groundwater levels. Water quality is affected by groundwater quality and the use of land on the shoreline.*


Photo: Callen Harty

THE GREEN BAY ECOSYSTEM

Lake Michigan's Green Bay is one of the largest freshwater estuaries in the world. Green Bay is characterized as an estuary because it functions as a nutrient trap, has very high biological productivity, and the water of its tributaries differs thermally and chemically from that of Lake Michigan. While representing only seven percent of the surface area and 1.4 percent of the volume of Lake Michigan, the bay receives approximately one-third of the total phosphorus loading within the Lake Michigan basin.

The head of Green Bay originates at the mouth of the Fox River, the largest tributary of Lake Michigan. The biogeochemical cycles in Green Bay are dominated by the nutrient inputs from the Fox-Wolf River watershed, whose area of 6,400 square miles is equivalent to one third of the Lake Michigan watershed. Approximately 70 percent of the phosphorus and suspended sediment load in the southern bay enters from the Fox River, including an estimated 330,000 tons of sediment annually and 1,210 tons of total phosphorus.

Public and private stakeholders have spent hundreds of millions of dollars in efforts to reduce pollution and restore habitat in the Green Bay ecosystem. Over the last 40 years or more they have made progress in restoring the ecological integrity of the bay and the many benefits it provides. Scientists and managers have recognized that the Fox River and the Green Bay ecosystem have become degraded because they are impacted by multiple stressors, not just one or two causal agents. Climate change poses a new kind of threat to the bay and its resources because it may alter the impact of the already existing stresses on the system.

Based on previous experience, the Green Bay Working Group assessed the potential consequence of climate change by evaluating the risk posed to the Green Bay ecosystem from regional shifts in temperature, precipitation and storm events. The relative magnitudes of risk to valued components of the ecosystem were estimated by examining the interactions among ecosystem stressors and the valued components of ecosystems. Working group members were assigned to one of five breakout groups to address the conservation targets:

- Northern pike
- Coastal wetland community
- Littoral zone community
- Lake sturgeon
- Benthic community

The groups applied five overarching principles of adaptive management:

- Reduce other non-climate stressors.
- Manage for ecological function and protection of biodiversity.
- Establish habitat buffer zones and wildlife corridors.
- Implement proactive management and restoration strategies.
- Increase monitoring and facilities management under uncertainty.

From these deliberations, one overarching adaptive principle emerged: Reduce other non-climate stressors and thereby increase the resilience and adaptive capacity of the system.

Figure 8. Map of Green Bay watershed
Source: The Nature Conservancy

Rivers and Streams

The state's thousands of miles of rivers and streams will also be affected by a changing climate. These impacts include changes in baseflow, more runoff with increased precipitation, and changes in fish habitat and land use.

Baseflow

To understand how projected climate change may affect hydrologic flows of rivers and streams in Wisconsin in the future, it is important to provide context by analyzing historic flows (figure 9). Similar to the historical temperature and precipitation trends analysis for 1950-2006 summarized in Chapter 1: *Climate Change in Wisconsin*, stream flow data collected by the U.S. Geological Survey for the same 57-year period from 48 stations in Wisconsin were analyzed in relation to spatial precipitation patterns. During the study period, precipitation increased approximately 10-15 percent on average across the entire state, with some areas of the state exhibiting much wetter trends and other areas exhibiting drier trends. Interestingly, the average statewide percentage change in annual flows observed for the 48 gauging stations over this same 57-year period was a comparable 14 percent, pointing to the strong coupling between basin precipitation and stream flow, with stream flows increasing in areas having increasing precipitation and flows decreasing in areas trending drier.

Baseflow: *The sustained low flow of a stream, usually groundwater inflow to the stream channel.*

Future annual precipitation projections for the next half century average in the 2-7 percent increase range. Thus, the increases in precipitation we have seen over the past half century are equal to, if not greater than, projected precipitation changes. Scientists cannot say with certainty that this will translate into a corresponding increase in annual flow for the state because seasonal precipitation patterns and extreme events are also expected to change, which will impact runoff amounts and consequent flows. In addition, tempera-

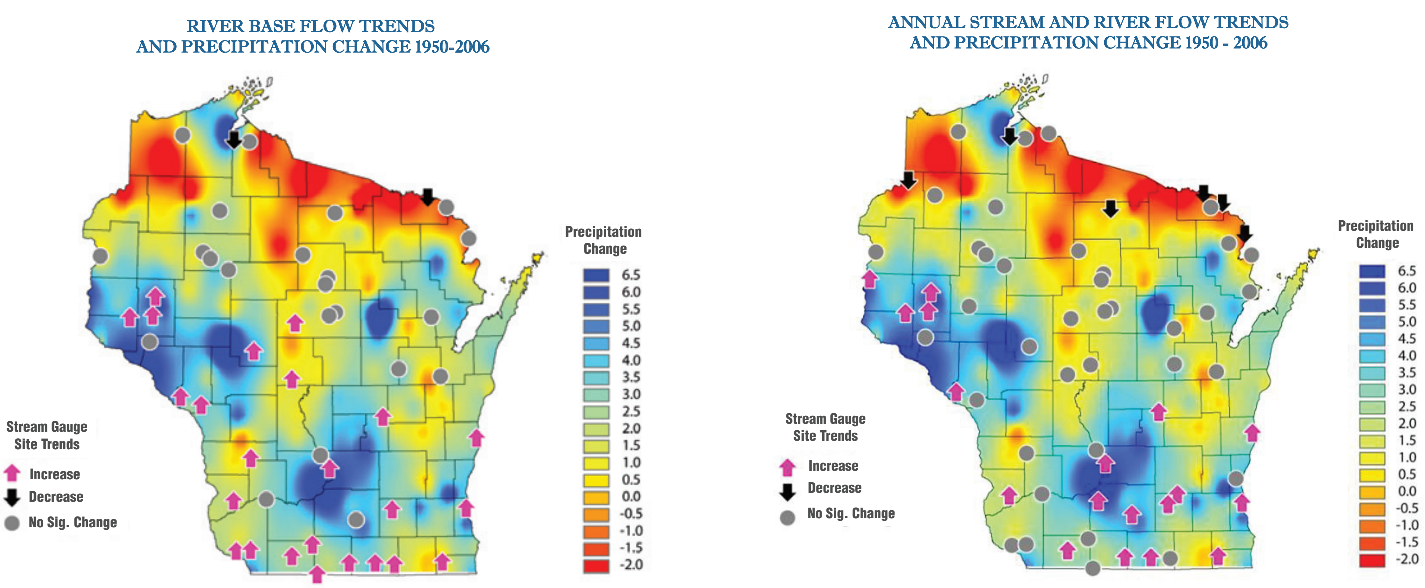


Figure 9. From 1950 to 2006, Wisconsin as a whole became wetter, with an increase in annual precipitation of 3.1 inches. This observed increase in annual precipitation was primarily in southern and western Wisconsin, while northern Wisconsin was drier. The southern and western regions of the state had increases in baseflow (left) and annual flow (right) between 1950 and 2006, corresponding to the areas with greatest increases in precipitation.

Source: Steve Greb, Wisconsin Department of Natural Resources, unpublished data.

tures are projected to increase, which will increase evaporation rates and decrease water yield to the receiving waters.

Where temperature increases, more evapotranspiration occurs and soil moisture declines, requiring an increased demand for irrigation from streams or groundwater in agricultural areas. When groundwater levels decrease, baseflow also decreases; therefore, groundwater-fed streams, which may provide habitat for coldwater fish species like brook trout, may be more profoundly affected.

Polluted Runoff

Increases in winter and spring precipitation will likely cause increases in large runoff events, leading to soil erosion, channel erosion, sediment and nutrient transport, increased eutrophication, habitat degradation and mobilization of contaminated sediment, all reducing surface water quality. Increased runoff will lead to flooding of small rivers and streams. In some instances streams that respond quickly to incoming and outgoing flows have a drier period between high flow periods, resulting in a "first flush" effect containing higher concentrations of sediment.

Changing rainfall patterns may impact flows on the Mississippi River and its tributaries, and large rivers, in general, will be affected. On rivers such as the Wisconsin River, where hydroelectric power is generated, the change in the timing of rainfall may affect the supply of electricity.

In Wisconsin's urban watersheds, the primary water quality issues relate to stormwater runoff or, as is the case in Milwaukee, combined sewer overflows. In both cases, changes in the magnitude and frequency of large daily or shorter-duration rainfalls are the most relevant. Climate change in Wisconsin is expected to result in modest increases in daily rainfall magnitude over the next century as well as increases in the frequency of large rainfalls. These changes will require greater investments in stormwater infrastructure for both new and existing development. We discuss the implications of climate change on infrastructure in Chapter 7: *People and Their Environment*.

In rural areas, nutrient and sediment runoff from agricultural lands is the most critical water quality concern. As is the case with urban watersheds, changes in the magnitude and frequency of large daily or shorter-duration rainfalls are most critical. But unlike urban areas, agricultural lands are particularly vulnerable to large rainfall events that occur in the spring when soil is bare. Hence, nutrient and sediment runoff from agricultural watersheds is likely to increase as a result of the combined impact of the projected increases in the magnitude and frequency of large rainfalls and in cold-weather precipitation. (See the Soil Resources Working Group report at www.wicci.wisc.edu for more detailed discussion.)

Eutrophication*: The process by which lakes and streams are enriched by nutrients and the resulting increase in plant and algae growth. This process includes physical, chemical, and biological changes that take place after a lake receives inputs for plant nutrients-mostly nitrogen and phosphorus-from natural erosion and runoff from the surrounding land basin. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).*

Fish Habitat

Another impact of climate change on rivers and streams is its effect on fish habitat. Rising water temperatures, changes in groundwater recharge and stream baseflow, and an increase in large runoff events from heavy storms may all affect stream channels or other habitat characteristics that fish require for survival. The details of research by the Coldwater Fish Working Group are discussed in Chapter 4: *Natural Habitats and Biodiversity*.

Flooding

In most watersheds outside urbanized areas, soil conditions are a more important factor in the extent of flooding than impervious surfaces. The occurrence of a large flood usually results from large rainfall events over soils that have reduced infiltration capacity because of soil saturation by previous rainfalls, snow melt or heavy frost. In Wisconsin, stream and river flooding can occur in all seasons, although the largest floods are usually in spring and summer. Expected increases in the magnitude and frequency of large rainfall events will very likely increase flood magnitudes in all Wisconsin streams and rivers, although the amount of increase will vary from place to place. The increase is likely to be the greatest in watersheds that are most vulnerable to flooding in late winter or early spring, when the likelihood of increased rainfall resulting from climate change is greatest.

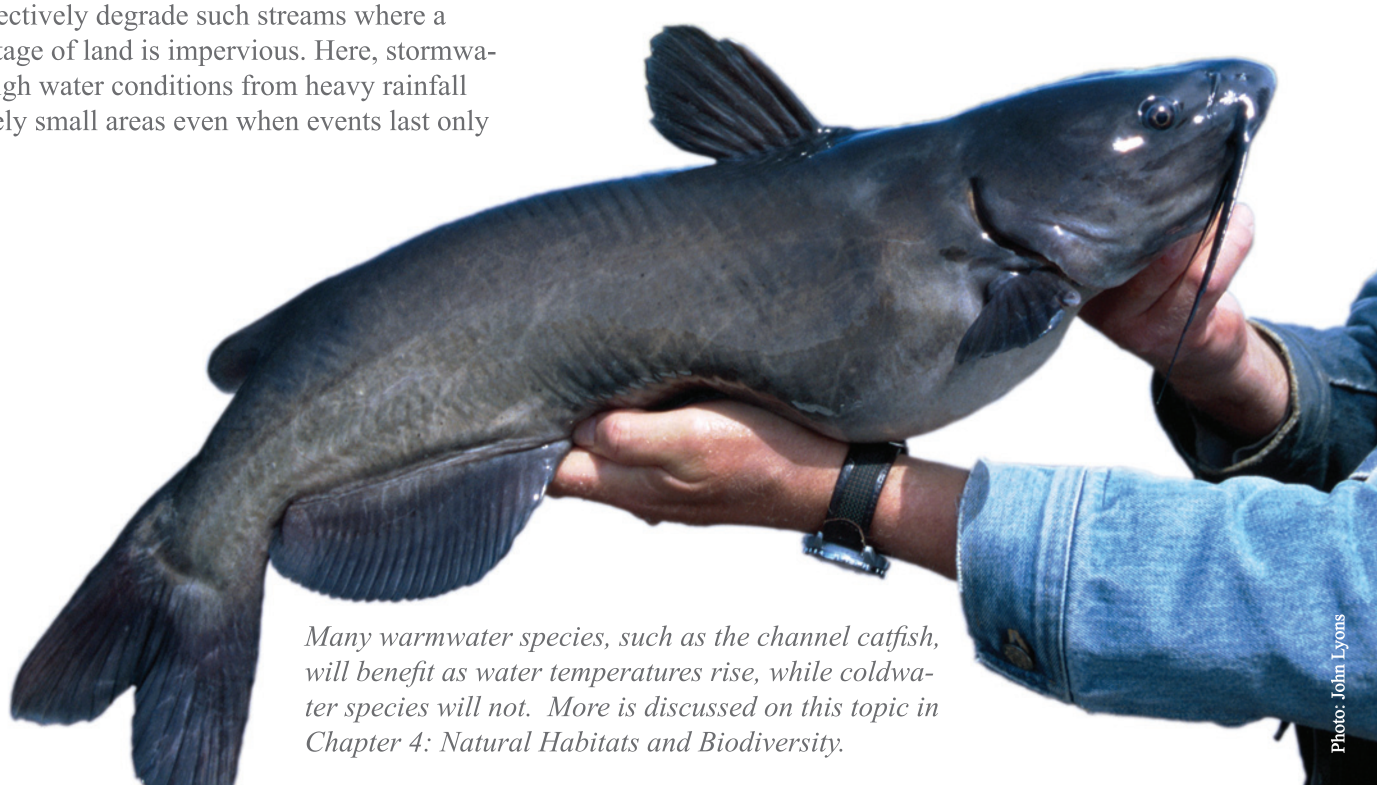
Land Use

Both rural and urban land use changes will influence water cycle components such as groundwater infiltration and resultant river flows. Given that annual flow characteristics are a product of multiple factors, it is difficult to predict changes in future flows. Hydrologic modeling on a basin scale, which simulates these dynamic hydrologic processes and accounts for changing land use conditions, temperature regimes, precipitation timing and characteristics, is needed to fully understand the impact of future climatic conditions on Wisconsin's river and stream flow regimes (see "Ongoing Research" in Chapter 9: *Moving Forward*). Large rainfall events will impact floodplains, which will have impacts on the built environment. Zoning codes and dam safety precautions may need to change.

Urban areas face additional challenges because urban streams are already stressed. An increase in precipitation will selectively degrade such streams where a high percentage of land is impervious. Here, stormwater causes high water conditions from heavy rainfall over relatively small areas even when events last only minutes to hours. Because large portions of an urban watershed are usually impervious, the peak rate of surface runoff is relatively unaffected by soil moisture conditions before the initiating storm. For these reasons, the design of stormwater infrastructure is usually based on single storm events. For urban stormwater, changes in the magnitude of rainfall at the daily or shorter time scale are the most relevant. It appears that climate change in Wisconsin will result in modest increases in daily rainfall over the next century, resulting in greater storm flows in urban watersheds.

Groundwater

Climate change will affect groundwater resources across the state. Increases in total annual precipitation, changes in the seasonal distribution of precipitation, increased frequency of intense rainfall events and increased average temperature all will affect groundwater quality and quantity. Given Wisconsin's diverse geology and hydrogeology, impacts will vary depending on site-specific conditions including soil and surface material characteristics, topography, depth to bedrock, depth to groundwater and land use practices. Climate change will have the most significant impacts on shallow groundwater systems, such as sand and gravel aquifers, whereas deep sandstone aquifers, such as those used by public water systems in Dane County and in southeast Wisconsin, will be less affected.



Many warmwater species, such as the channel catfish, will benefit as water temperatures rise, while coldwater species will not. More is discussed on this topic in Chapter 4: Natural Habitats and Biodiversity.

Photo: John Lyons

Recent Trends

Only a few long-term groundwater-level records exist in Wisconsin. These records do not demonstrate consistent long-term trends in water level; however, fluctuations of water levels ranging from annual to many years occur in each well. These monitoring wells from northern and southern Wisconsin appear to follow similar patterns over some periods (1965-1990) but follow divergent patterns in others (1950-1965 and post-1990) (figure 10). During the past few years, groundwater levels in the south have increased because of several wet years, whereas water levels in the north, especially north central areas, have decreased during drought. Records of groundwater and surface-water levels from specific areas demonstrate similar fluctuations; however, the long-term trends appear to be more dramatic in seepage lakes.

Groundwater Recharge

Generally, climate change impacts will occur as changes in groundwater recharge, which in turn will lead to other water resource impacts. An increase in precipitation normally corresponds with an increase in recharge and, ultimately, a rise in groundwater levels; however, concurrent increases in temperature and resultant changes in land use and water use patterns may offset any increase in recharge. Certain areas of the state could actually experience declines in groundwater levels. As time goes on, temperature and increased evaporation may dominate changes in precipitation, resulting in lower levels in general.

Groundwater recharge in the spring depends largely on the interplay between the amount of winter snowpack, the timing of spring thaw and the timing of the opening of leaf buds, all of which are temperature-dependent. Climate change projections call for increased winter precipitation, but because of the predicted warmer winter temperatures, there is also greater likelihood that an increased amount of the precipitation will fall as rain rather than snow. If significant rain events occur during the winter and the surface of the ground is frozen, much of the rain will run off and will not contribute significantly to groundwater recharge. Warmer temperatures could also result in shorter periods of frozen ground conditions, leading to longer periods of time when the melting snowpack or rain could infiltrate and ultimately increase groundwater recharge. Soil type, soil moisture, vegetation and frost are critical factors that help determine the amount of recharge versus runoff.

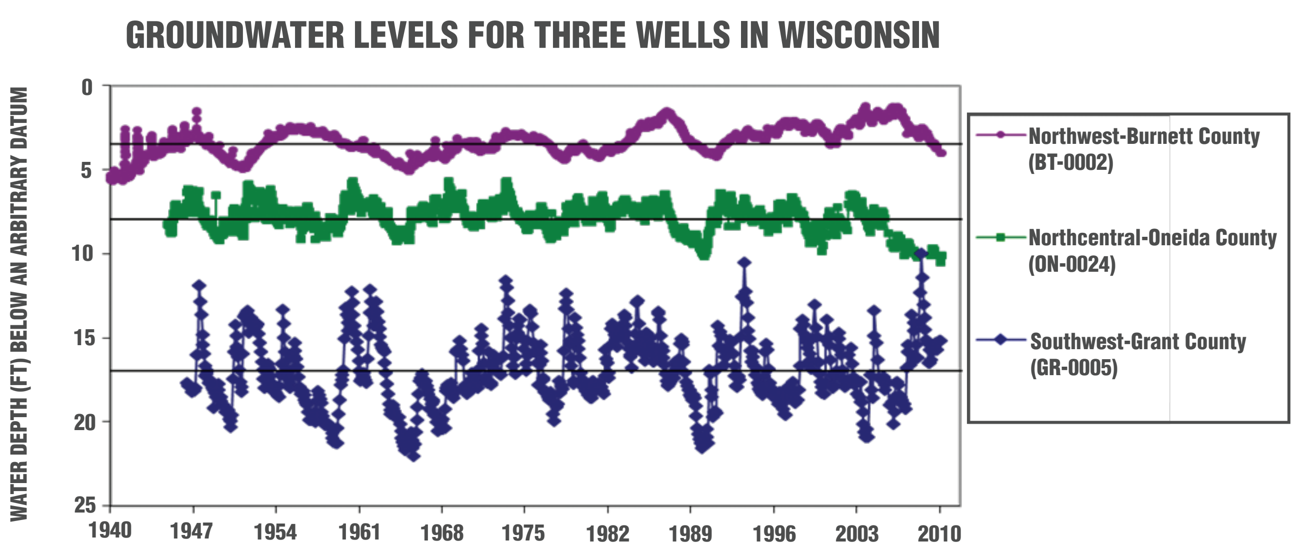


Figure 10. Groundwater levels for three wells in Wisconsin show that oscillations in water level can range in length from annual to multi-decadal.

Source: Dale Robertson, U.S. Geological Survey.


Photo: Peter Gorman

Groundwater flooding in Spring Green, Wisconsin, July 12, 2008.

In contrast, a longer growing season and warmer summer temperatures would result in a decrease in groundwater recharge during the summer months. With a longer growing season, plants would use all available soil moisture for a longer period of time and soils would begin to dry out earlier in the year, resulting in a shorter effective period of recharge. All of these effects would lead to lower groundwater levels and less groundwater discharge to surface waters, potentially leading to reduced summer flows in streams and lower lake levels.

Significant changes in groundwater recharge could result in dramatic changes in the dynamics of lake, stream and wetland systems. Decreased recharge would result in reduced flow from springs, lower baseflow in streams, loss of some wetlands and lower lake levels in most lakes, but especially groundwater-fed seepage lakes situated relatively high in the landscape. On the other hand, an increase in recharge would produce the opposite effects and, if taken to an extreme, could result in increased flooding and conversion of some wetland systems to lakes.

Groundwater Flooding

More frequent large-precipitation events may result in localized areas of groundwater flooding, especially where groundwater recharge occurs quickly, depth to groundwater is normally fairly shallow and there is little topographic relief. Frequent high-intensity storms could cause groundwater levels to rise above the ground surface, leading to flooding conditions.

Areas with high groundwater recharge rates are most vulnerable to negative impacts if these areas are built over during prolonged dry cycles or drought and the groundwater table subsequently rises (sometimes as much as 12 feet in only a few weeks) given a significant amount of precipitation (see Spring Green sidebar).

The human impacts of flooding can be great, including flooding of basements, homes and septic systems. This can lead to other environmental impacts if the septic systems are near other surface waters or sources of drinking water. We discuss these human impacts in Chapter 7: *People and Their Environment*.

GROUNDWATER FLOODING NEAR SPRING GREEN

In the summer of 2008, about 17 inches of rain fell in a 10-day period in southern Wisconsin, resulting in overflowing stream banks and groundwater flooding. About 4,300 acres of land near Spring Green – beyond the Wisconsin River floodplain – became inundated with water that rose from the ground and overtopped the land surface.

The land remained underwater for more than five months. No amount of pumping would reduce the water level because there was no place for it to drain. Computer modeling and data from nearby monitoring wells showed that the groundwater level in the shallow aquifer had risen by as much as 12 feet. Residents in 28 homes left uninhabitable moved out and received compensation from the government for the value of their homes.

Scientists and policy-makers can use real-life weather events like the Spring Green example to help predict where groundwater flooding may occur in other geologically similar areas of the state. The Wisconsin Geological and Natural History Survey is conducting research that will apply a series of climate forecast and hydrologic models to selected landscapes that are vulnerable to water table rise and groundwater flooding.

Photo: Madeline Gotkowitz

Impacts on Groundwater Use and Interactions with Land Use

Increased temperatures will lead to an increased length in the growing season in Wisconsin and higher rates of evapotranspiration during the summer and early fall months. If current statewide cropping practices continue, a longer growing season without significant increased precipitation during the summer months could lead to increased reliance on irrigation systems, putting greater demand on groundwater resources, such as in the Central Sands region.

If agricultural practices change in response to changing climatic conditions, the impacts on groundwater could be exacerbated. The longer growing season could result in more land being put into agricultural use and, therefore, more land area being subject to nutrient and pesticide applications. This could lead to increased risk of contamination of both surface water and groundwater. For example, if development of biofuels using corn as a source were to expand, additional irrigated acreage would likely be converted to growing corn, increasing groundwater use and petroleum-based inputs and ultimately resulting in even greater adverse impacts on groundwater resources. On the other hand, if cropping patterns were to switch to more drought-tolerant varieties, the reliance on groundwater would diminish and the impacts would be less than currently projected.

As with agriculture, groundwater withdrawals by municipal water systems would also be expected to increase with elevated summer temperatures and greater demand for water, putting additional pressure on scarce groundwater resources and potentially affecting surface waters.

Groundwater Quality

Climate change has the potential to affect the quality of groundwater through a number of different mechanisms. Less recharge water could mean less dilution of contaminants and higher levels of total dissolved solids in groundwater. In situations where groundwater recharge occurs rapidly, a rising water table will reduce the distance between land surface and groundwater, making the groundwater more susceptible to contamination from sources such as septic systems. Higher winter temperatures and increased winter precipitation could result in more frequent icing conditions on roadways, leading to increased application of road salts. This would create greater potential for contamination from chlorides.

Shallow groundwater is typically the same temperature as the mean annual air temperature. In shallow wells, the expected increase in water temperatures could lead to more microbial activity, biofouling of wells and an overall decrease in water quality.

Finally, an increased frequency in intense precipitation events could lead to inundation of drinking water wells, which could result in groundwater contamination. Surface water that enters groundwater through wells and other conduits can lead to oxidation of sulfides, increased microbial activity, increased sulfate and releases of arsenic and heavy metals.

Wetlands

Wetlands can act as flood storage areas, so where wetland acreage exists, flooding will have a less negative impact. Wisconsin has lost about 4.7 million of the 10 million acres of wetlands that were present in 1848, mostly from farm drainage and filling for development and roads. While the conversion of wetlands to other uses has slowed, they continue to be destroyed and degraded by invasive plants, overuse of groundwater and increased stormwater runoff from development.

Changes in Hydrology

If winter and spring runoff increases, the area of some wetlands may increase, but there may also be a shift to wetter, deeper wetland types. We can also expect to see an increase in flooding duration of wetlands in low-lying areas. Ephemeral ponds will have higher initial water levels. Some will become connected with other water bodies, and fish will populate and prey on or

Photo: Richard Lathrop

Pheasant Branch Conservancy wetland and spring system, Middleton, Wisconsin.

compete with amphibians, reducing their reproductive success.

Increased spring runoff may also increase streambank erosion, making stream channels wider and deeper, and they may become disconnected from wetland-rich floodplains. As these streambeds cut downward and improve drainage they lose the associated benefits of floodplain wetlands for sediment trapping, nutrient retention and aquatic habitat.

An increase in infiltration may enhance the extent of groundwater-fed wetlands, but it depends on the timing of precipitation events. If winter rains are accompanied by a longer frost-free period, recharge could increase and shift the water budget toward larger groundwater input, benefiting saturated-soil wetlands. If winter rains fall on frozen ground, however, winter flooding could greatly increase delivery of pollutants to downstream wetlands and result in little or no recharge.

Responses to increased air temperatures will vary depending on the degree of groundwater inputs to a wetland. Shallow wetlands could dry out earlier in the summer with greater evaporation and warmer water. Wetlands with high levels of groundwater inputs are less likely to dry up from evapotranspiration, but their size may decrease.

Increased Sediment and Nutrient Loads

Shifts in both temperature and precipitation will change the nutrient dynamics in wetlands. Increased precipitation could cause some wetlands and hydric soils to release phosphorus, while methane emissions may increase in others, such as the sedge meadows in southern Wisconsin. Increased summer droughts and evapotranspiration will increase decomposition and change nutrient dynamics, leading to, among other things, an increase in carbon dioxide emissions.

CHALLENGES TO RESTORING DRAINED WETLANDS

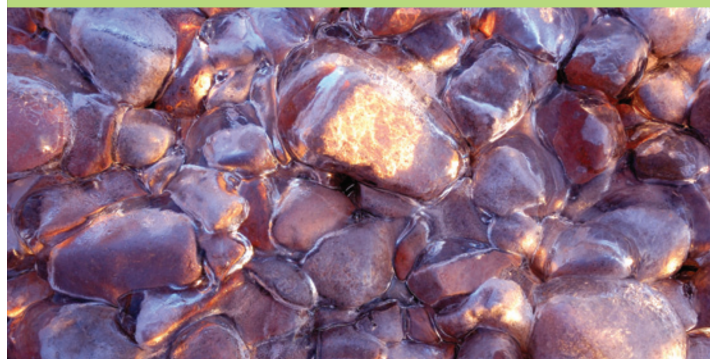
Wetlands are an essential tool for managing high water, providing flood storage capacity for overflowing streams and rivers and precluding runoff that would occur if low-lying areas were to be developed. By restoring wetlands that were previously converted to croplands and by preventing the loss of existing wetlands, we can increase our capacity for adapting to future high-water conditions. However, wetlands that were drained for agricultural use prior to 2005 are exempt from regulation under the Clean Water Act and state wetland laws even when agricultural production ends. Once agricultural production is discontinued the landowner can continue to maintain the property's drainage system (surface and subsurface) to prevent the reestablishment of wetlands at the site. If the drainage is maintained, the site remains outside the jurisdiction of the Clean Water Act and the landowner can develop the site. However, if the drains are not subsequently maintained, the land might revert to wetland conditions, and surface or groundwater flooding of areas where development has taken place. Suburban and rural development where drained wetlands has resulted in significant property damage.

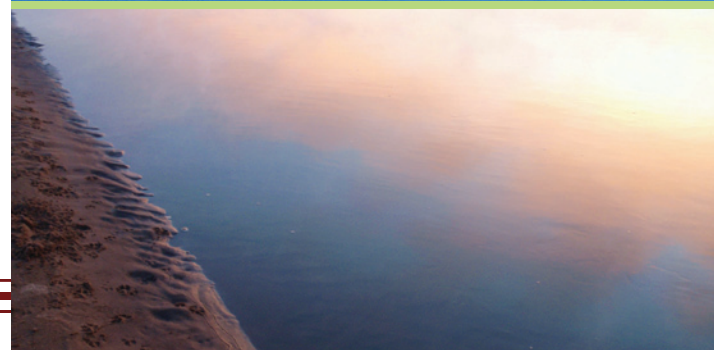
Shifts in plant, aquatic and animal communities and the proliferation of invasive species are also concerns that wetlands will face as climate continues to change, and these impacts are discussed in Chapter 4: *Natural Habitats and Biodiversity*. In Chapter 6: *Coastal Resources*, we discuss climate change impacts on coastal wetland ecosystems.

Impacts on People and the Built Environment

Hydrologic responses to climate change will also have many impacts on the built environment and on human health. With more frequent heavy rainfall events, current infrastructure, such as underdesigned stormwater detention basins, could be overwhelmed. Other existing infrastructure may also be taxed, such as sanitary sewer overflow systems that will not be able to keep pace with increased volumes of stormwater. These impacts are discussed in greater detail in Chapter 7: *People and Their Environment.*

Source material for this chapter was drawn from the Central Sands Hydrology, Green Bay, Stormwater and Water Resources Working Group reports, available online at www.wicci.wisc.edu.





Adaptation Strategies

The great diversity of water resources in Wisconsin and the variations in impacts on quantity and quality from region to region lead to a wide range of possible adaptation strategies. In keeping with the organizational framework presented in Chapter 2*: Understanding Adaptation*, we present here several adaptation strategies relevant to Wisconsin's water resources. (Please see the working group reports at www.wicci.wisc.edu for a more detailed discussion of adaptation strategies.)

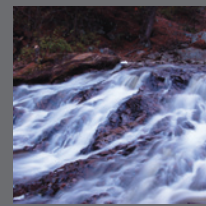
ADAPTATION

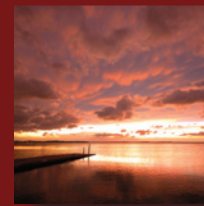
TAKING ACTION

- **Restore prior-converted wetlands in upland areas to provide storage and filtration and to mitigate storm flows and nutrient loading downstream. Protect and restore wetland hydrologic regimes. Control polluted runoff to wetlands.**
- **Promote integrated water management planning using long-term projections of supply and demand, tied to land use and economic growth forecasts. Encourage large water users to locate in areas with sustainable water sources (for example, near large rivers or the Great Lakes). Encourage water conservation (rural and urban) through incentives and regulation.**
- **Enhance infiltration in headwater areas, near watershed divides, and in areas with lower groundwater levels by reducing impervious surfaces in urban/riparian areas and improving land management practices. Protect recharge/infiltration areas and riparian buffers from overland flow of polluted runoff.**
- **Incorporate water management strategies based on climate projections into farm-based nutrient management plans. Resize manure storage facilities, wastewater facilities, stormwater drains, and infrastructure to accommodate increased storm flows to protect water quality. Complete and implement total maximum daily load (TMDL) plans and best management practices, particularly using stream buffers.**
- **Continue current and proposed regulatory controls for nutrient and solids loading (for example, TMDLs), biochemical oxygen demand, and nonpersistent toxic substances. Continue existing programs for identification and remediation of legacy pollutants. Update the waste load allocation rule (NR 212) to determine need for adjustment resulting from climate change. Examine policies and regulations protecting lands below the ordinary high water mark.**
- **Continue existing programs to restrict spreading of dreissenids (zebra and quagga mussels), and consider seed bank manipulation to counter Phragmites invasions along Great Lakes shorelines. Encourage regulatory activities aimed at preventing future invasions of exotic and invasive species.**
- **Enhance and restore shoreline habitat (coarse wood, littoral and riparian vegetation, bio-engineered erosion control) to withstand variations in water levels.**
- **Develop statewide standards for blue-green algal toxins and take appropriate action to protect public health.**

BUILDING CAPACITY

- **Improve models relating weather, soil hydrology, groundwater hydrology, and groundwater discharge to streams. Use these models to evaluate vulnerabilities and potential adaptation strategies. Use updated models to predict groundwater impacts on development.**
- **Incorporate climate change scenarios into modeling efforts, watershed management and restoration plans, then engage in community planning. Create or designate new surface flood storage areas (for example, wetlands) to mitigate high-water impacts. Identify, map and prioritize potentially restorable wetlands in floodplain areas.**
- **Provide local units of government with technical and financial assistance to assess and mitigate their vulnerabilities to potential high-water conditions caused by**





Conclusion

Wisconsin is a water-rich state. Our lakes, rivers, groundwater and wetlands are critical components of our state's natural habitats, our coastal communities, industry, agriculture, recreation and public health. Impacts on one part of the water cycle will affect the quality and quantity of the rest. Our climate is changing, and increasing temperatures and shifting precipitation patterns are already impacting – and will continue to impact – Wisconsin's water resources. These impacts trigger subsequent changes in aquatic ecosystems and human communities. Addressing climate change in Wisconsin necessitates a strategic approach to adapting to impacts on our water resources. We can begin by relying on and expanding tools and policies that are already in place.

STRATEGIES

today's and future climates. For example, examine the adequacy of wastewater treatment systems and stormwater infrastructure to accommodate climate change conditions.

- **Provide assistance to local governments by developing regional continuous hydrologic simulation models for both surface water and groundwater, increasing the capacity of the Wisconsin Geological and Natural History Survey, partnering with the U.S. Geological Survey, or funding private studies.**
- **Develop rapid response planning and implementation methods to improve existing aquatic invasive species control programs. For example, evaluate the potential benefits of temporary lake drawdowns and investigate the possibility of isolating the Great Lakes from oceangoing vessels via cargo transfer.**

COMMUNICATING

- **Propose and adopt a framework for managing groundwater withdrawals that is consistent with societal goals for surface water health.**
- **Adjust and modify expectations about lake water levels. Recognize that some lakes may not be suited for all uses (for example, recreational boating in shallow waters or during low-water periods).**
- **Account for changing water levels in planning and zoning standards for lakeshore development. Establish a clear understanding of the ordinary high-water mark.**
- **Develop guidance to control the amounts and types of artificial riparian modifications to shoreline and runoff conveyance mechanisms.**
- **Continue exotic and invasive species education/awareness programs for boaters, anglers, and others.**
- **Disseminate findings from climate assessment studies to water resource managers, municipalities, academics and conservation and environmental organizations.**

FILLING GAPS

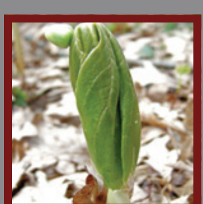
- **Improve systems for monitoring lake and groundwater levels and stream flows. Collect stream monitoring data (for example, water temperature, flow and fish abundance) to test predictions of the effects of climate change on the distribution of coldwater fish in streams and determine how changes in air temperature and precipitation effect changes in stream temperature and groundwater input to streams.**
- **Create a surveillance program to collect data and identify ways in which climate change processes may increase the occurrence of human and animal exposures to harmful algal blooms. Increase monitoring of inland beaches for blue-green algal toxins and associated water quality to improve predictive capacity.**
- **Encourage research and regulatory attention to pollutants of emerging concern. Repeat the Green Bay Mass Balance Study of PCB fate and transport and food web modeling for climate change conditions.**
- **Investigate the need for a targeted strategy to manage spring runoff. Assess the effectiveness of conventional best management practices and support development of new methods.**

CHAPTER FOUR

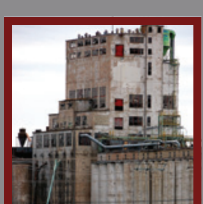
NATURAL HABITATS

Wisconsin Landscapes

Changes in Natural Habitats



Impacts and Vulnerabilities



Non-Climate Stressors

Adaptation Strategies

Photo: Darren Bush

AND BIODIVERSITY

Wisconsin is rich in natural resources. Our cultural identity and economy are tied to the wealth of species – both plants and animals – that inhabit our state. With 16 million acres of forested land, more than 1,800 native plant species, more than 500 terrestrial animal species, more than 80,000 miles of streams and rivers, and more than 800 miles of Great Lakes coastline, biological diversity abounds in our state. These varied and diverse natural resources serve vital roles both in their ecosystems, by providing benefits such as soil formation and water purification, and in our society, by providing aesthetic, economic and recreational value and by contributing to our food supply.

Climate change is impacting these ecosystems and their inhabitants by affecting individuals and communities of species and changing habitats and the processes that act within them. Rising temperatures, shifting precipitation patterns, and an increasing number of heavy rainfalls set off ripple effects that bring physical changes to natural habitats, triggering biological responses among the plant and animal species in them. Climate change is manifested differently across habitats, ecosystems and the state, with direct and indirect impacts resulting in "winner" and "loser" species, as some are particularly vulnerable to changes in climate and habitat while others are more resilient. While some species will indeed fare better in a warmer Wisconsin, scientists expect the majority of species influenced by climate change to fare worse.

__Ecosystem__: Short for ecological system. A community of living organisms and its environment, considered together as a unit. Ecosystems are characterized by a flow of energy that leads to trophic structure and material cycling (that is, an exchange of materials between living and nonliving parts).

In this chapter, we provide general descriptions of the northern and southern regions of the state, each with its own distinct geology, vegetation, wildlife and land use patterns; discuss the impacts of climate change on the natural habitats of these regions; and describe the vulnerabilities of various plant and animal species. This is the first assessment of climate change impacts on Wisconsin's natural habitats and biodiversity; therefore, these analyses are preliminary. As scientists continue to analyze the downscaled climate data, which are presented in Chapter 1, their findings about the climate impacts on natural habitats and biodiversity will be incorporated into future reports.

Wisconsin Landscapes

Geography, geology and habitat types vary across Wisconsin. More than half of the landscape is forested, with agriculture taking a close second in percentage of land cover. The northern and southern regions of the state are divided by the Tension Zone (figure 1), a swath of land running northwest to southeast that marks the transition in vegetation, wildlife, geography and climate between these two regions of Wisconsin.

Northern Wisconsin

Northern Wisconsin is predominantly forested, characterized by a mix of conifers and hardwoods. Grasslands, agriculture and urban areas are present to a lesser extent. The region contains the headwaters for streams flowing north to Lake Superior, east to Green Bay and Lake Michigan, and south to small and large stream systems such as the Wisconsin and St. Croix rivers. Just south of the northern coastal region lie the lowland conifer forests of tamarack and spruce growing in ecologically diverse peat swamps.

An abundance of inland lakes, formed as the glaciers retreated to the north, dot the central portion of northern Wisconsin. Pines grow on the dry, sandy soils of the outwash plains among grasses, berries and lupine or along rivers and glacial lakes also populated with stands of hardwood trees such as maples and conifers such as hemlocks and balsam fir.

***Tension Zone**: A transition zone that stretches across Wisconsin from northwest to southeast in an S-shape, forming the northern boundary of many species' ranges, both plant and animal. The Tension Zone divides the state into the two major ecological regions.*

The northeastern landscape contains the Lake Winnebago watershed, feeding Wisconsin's largest inland lake, as well as extensive wetlands, which are home to rare plant and animal species. The region is forested with an abundance of aspen and northern hardwoods. The species that inhabit the wetlands of the northern regions are very sensitive to temperature and water level changes, and the lakes are common nesting and breeding grounds for a diverse group of water birds, including common loons and black terns.

Southern Wisconsin

As we move southward through Wisconsin, geological conditions as well as temperature and moisture conditions change, leading to changes in landscapes, habitats and land use. Landscapes shift to agricultural fields, dotted with lakes and wetlands, remnants of prairies and savannas, and a mosaic of broadleaf forests of oak, hickory, maple and other species.

The central part of Wisconsin, known as the Central Sands, is mostly flat, punctuated by moraines and outcrops. This region is characterized by extensive

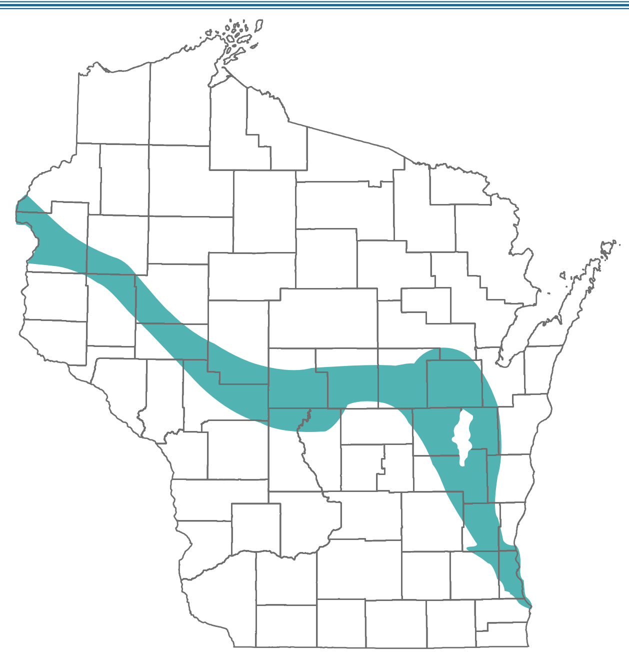


Figure 1. Tension Zone





wetlands and headwaters for coldwater streams, and the soils are sandy with some pine and oak forests. Agriculture dominates as the primary land use, and the region also supports forestry, cranberry production, recreation and wildlife management. The sandy soils and aquifers in the region make the system sensitive to variations in hydrology so that changes in groundwater levels can be pronounced and can quickly affect forests and other plant communities in both upland and lowland habitats. Rivers and floodplains provide extensive, contiguous habitats for many species and act as travel corridors, establishing connectivity with other ecological landscapes.

The western part of southern Wisconsin, known as the Driftless Area, was bypassed by glaciers during previous ice ages and is marked with ancient cliffs, deep valleys and steep hills that contain plant species – including glacial relict species – unique to the area. High ridges and valleys, with hardwood forests of oak, hickory, sugar maple and basswood, define the landscape. Agriculture is important here, and timber is harvested from the steep slopes. Many rivers, abundant in brook trout and brown trout, drain this region, forming wetlands as they join the Mississippi River floodplain.

The southwest – once mostly prairie and oak savannas – is now a mix of fields and pasture with sporadic oak trees spreading their limbs across the landscape. Coldwater streams are abundant. These grassland regions harbor many rare prairie and savanna plants as well as grassland birds, invertebrates and other animal species. Relict stands of hemlock grow along cool- and warmwater stream systems together with stands of hardwoods. Seventy percent of land in this region is used for agriculture.

In southeastern Wisconsin, glacial plains support a mix of urban and agricultural areas with occasional patches of forest. Large inland lakes, such as the Yahara chain in Dane County, Lake Geneva, Lake Koshkonong and others, dot the landscape; however, the ecosystems in this region have been degraded by deforestation, agriculture and urban development.

The northern Kettle Moraine – one of southern Wisconsin's major repositories of biodiversity, including many rare species – straddles the Tension Zone and features extensive forests, conifer and ash swamps, lakes, springs, marshes and a large stretch of the Milwaukee River. This area is an important refuge for bird species that live and nest almost exclusively within forests.

Coastal Regions

The Great Lakes coastline makes up a large portion of our state border. The wetland, bluff, beach and dune habitats differ from the rest of the state because the large water bodies of Lake Superior, Lake Michigan and Green Bay retain heat, creating "lake effect" microclimates. Lake Superior influences the temperature and precipitation patterns along its shores, creating microclimates with warmer winters and cooler summers compared to the rest of northern Wisconsin. These coastal habitats support a large number of rare plant and animal species. We discuss the climate change impacts on coastal regions and resources in the Chapter 6: *Coastal Resources*.

Habitat*: The place where an organism lives and its surrounding environment, including its living organisms and nonliving components (such as soil, rocks, air and water). Habitat includes everything an organism needs to survive.*

Changes in Natural Habitats

The distribution and abundance of each plant and animal species throughout the landscape is governed by its unique sensitivities to climate conditions, physical characteristics such as geology, soil type and topography, interactions with other species, and human activity. While from a human perspective we view natural communities as stable compositions, in the long term they are actually temporary associations of species subject to fluctuations in abundance and distribution as species respond to changes in their environments and climatic conditions.

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Photo: Jim Lorman

Physical changes in the environment, including those resulting from changes in climate, lead to an array of biological responses, some of which expose vulnerabilities and impacts within natural communities and habitats. While ecosystem responses to climate change are manifested differently across the varying habitats and ecosystems of the state, they do occur statewide. In the following sections we present some of the direct and indirect effects of climate change, the likely biological responses and the potential impacts and vulnerabilities.

Phenology: *The effect of seasonal cycle on biological phenomena such as flowering, breeding or migrating; the relationship between a regularly recurring biological phenomenon and climatic or environmental factors that may influence it.*

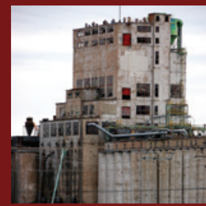
Early Onset of Spring

The earlier arrival of spring is one of many effects of climate change on the physical and biotic characteristics of Wisconsin's natural habitats and ecosystems. Across the state, temperatures are warming earlier in the year than in decades past. In the last 57 years, we have seen a statewide compression of the length of winter as spring weather arrives six to 20 days earlier than it used to, extending the growing season by two weeks. Trees are budding and flowers are blooming sooner, and the last of the ice is disappearing from the lakes earlier. Climate scientists and ecologists project this trend will continue.

These changes in growing season and the early onset of spring will affect the timing of life-cycle

Photoperiod: *The daily cycle of light and darkness that affects the behavior and physiological functions of organisms.*




BIRD MIGRATION	VEGETATION
Geese arrival: 29 days earlier	Baptista first bloom: 18 days earlier
Cardinal first song: 22 days earlier	Butterfly weed first bloom: 18 days earlier
Robin arrival: 9 days earlier	Marsh milkweed first bloom: 13 days earlier

Table 1. Evidence of earlier arrival of spring in Wisconsin from 1936-1998.

Source: Bradley et al., 1999. Phenological changes reflect climate change in Wisconsin. Proc. Natl. Acad. Sci., 96: 9701-9704.

events, or the *phenology,* of plants and animals. This means that the timing of biological events over the course of the year is shifting and will continue to shift for many species. Some plants and animals respond to temperature as a cue to initiate growth and reproductive activities, and others depend on photoperiod or respond to each other's life-cycle cues. These relationships may be thrown out of sync as climate change continues.

Migration behavior among wildlife is shifting in response to advances in signals of spring such as earlier snowmelt, warmer temperatures, more precipitation and other moisture signals. This shift is already in progress for some species in Wisconsin. In a recent study by Nina Leopold Bradley and others, researchers noted a shift in the phenology of 17 species in the state (table 1). One species, the Canada goose, now arrives a month earlier than in the 1930s and, according to the Wisconsin Department of Natural Resources, is now a year-round resident in southern portions of the state. In some instances, the phenological shift of a species may have cultural or economic implications. For example, year-round residence of the Canada goose may degrade water quality and increase damage to corn crops in the state.

Rising Water Temperatures

Temperature increases mean more than just warmer weather. As air temperatures rise, so will the temperature of water in streams, rivers, lakes and, to a lesser extent, groundwater.

Wisconsin is renowned for its abundance of coldwater streams that contribute to our state's cultural identity and legacy. These streams, which dissect the landscapes of northern Wisconsin and the western Driftless Area, provide fisheries for brook trout and brown trout. But these trout are very sensitive to changes in water temperature and can survive and reproduce only if temperatures remain below a certain threshold. For example, with an increase in the average summer air temperature of just over 5º F, models predict that rising stream temperatures could eliminate up to 95 percent of suitable brook trout habitat across the state.

Many warmwater species, including several game fish species such as channel catfish, smallmouth bass,

Migration*: The periodic seasonal movement of birds or wildlife from one geographic region to another, typically coinciding with available food supplies or breeding seasons.*

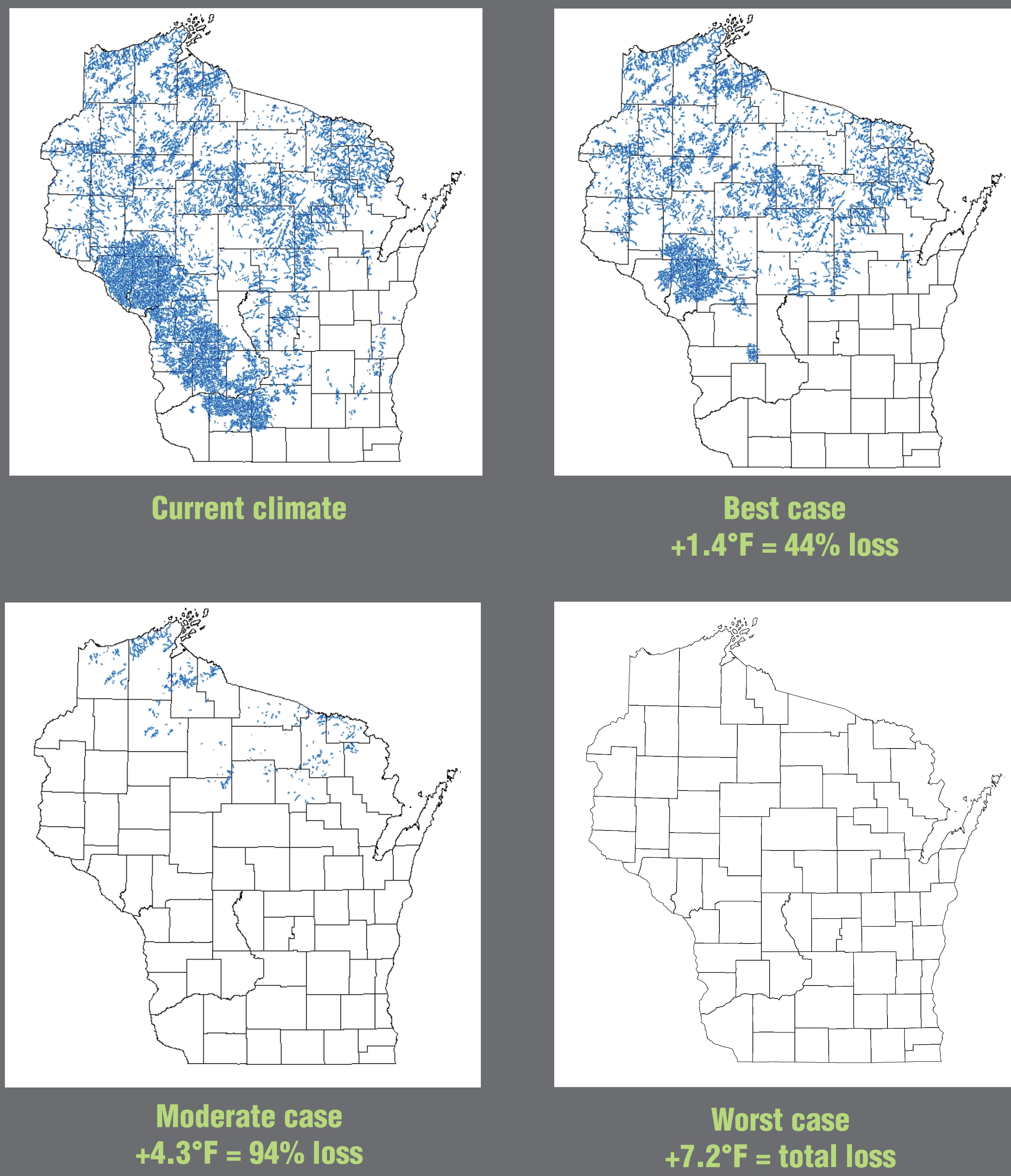
HOW WILL CLIMATE CHANGE IMPACT WISCONSIN'S BROOK TROUT?

Wisconsin is recognized for its abundance of coldwater streams, which includes more than 10,000 miles of classified trout streams. Anglers make a significant contribution to our local and state economies in their pursuit of trout and other coldwater fishes. Expected climatic changes across the state threaten the viability of Wisconsin's inland trout resources and the angling community that depends on them. The Coldwater Fish and Fisheries Working Group used watershed-scale models to predict the changes in coldwater habitat and distributions of coldwater fishes that would occur under three different climate change scenarios.

The working group ran models for each stream reach in the state under current climate conditions plus three mid-century climate warming scenarios projected for Wisconsin: 1) a "best-case" scenario (B1) in which summer air temperature increased by slightly more than 1.8° F and water temperature by 1.4° F; 2) a "moderate-case" scenario (A1B) in which air temperature increased by 5.4° F and water temperature by 4.3° F; and 3) a "worst-case" scenario (A2) in which air temperature increased by 9° F and water temperature by 7.2° F. The group analyzed the impacts on brook trout, brown trout, and mottled sculpin. The results show that climate change will likely cause reductions in all coldwater habitats and fish species in Wisconsin because increases in air temperature produce increases in water temperatures in nearly all coldwater streams. Brook trout are expected to take the biggest hit. Under the worst-case climate change scenario, brook trout are projected to be completely lost from Wisconsin streams. The moderate scenario brings a 94 percent loss, and even the best case leaves Wisconsin with 44 percent less brook trout habitat by mid-century. Under the worst-case scenario, brown trout habitat is expected to decrease by 88 percent, and mottled sculpin by 95 percent. The models show these losses occurring evenly across the state and not concentrated in any particular geographic region.

Differences in the characteristics of streams and their watersheds lead to variance in the capacity to buffer changes in water temperature from stream to stream. This brings opportunities for landowners and natural resource managers to offset the impacts on trout habitat through land, riparian and water management strategies, including stream restoration. A triage approach can help determine which streams may face inevitable losses of coldwater fishes and which streams could be maintained as viable trout habitat through the careful implementation of adaptation strategies. A proactive application of adaptation strategies will help protect Wisconsin's coldwater fishes and fisheries from the impacts of our changing climate. To learn more about the findings of the Coldwater Fish and Fisheries Working Group, see its full technical report at www.wicci.wisc.edu.


Photo: Matt Mitro



Predicted distribution of brook trout in Wisconsin streams under current climate conditions and predicted losses under three climate-warming scenarios for Wisconsin by mid-century.

Photo: Kathryn Kirk

Reduced snow cover threatens plant and animal species that are adapted to and rely on snow cover for their winter survival. Climate projections indicate that snow cover will drop by about 40 percent in northern Wisconsin over the next half century. Snow is a moisture source and a thermal insulator. For example, it provides an insulating cover for the fragile root systems of lowland conifers. Some wildlife, such as the American marten, rely on hollow trees and other areas in and under layers of snow for insulation and protection from predators. Less snow in future winters will present martens with greater risks of predation as well as more competition for their food resources.

largemouth bass and black crappie, will benefit from rising stream temperatures. And nongame fish, including various minnows and darters, will gain habitat as well. The length of stream habitat that warmwater fish are projected to gain, however, is three times less than the length of habitat coldwater fish stand to lose. Moreover, most of the coldwater streams that scientists expect to become warmer are too small to be suitable for warmwater game fish. This means that as these streams get too warm for coldwater game fish such as brook trout and brown trout, there will be no warmwater game fish that can fill the niche and provide a recreational fishery.

Fish are not the only wildlife that will be affected as stream temperatures rise. For example, Wisconsin is one of the few remaining states where the Hine's emerald dragonfly, a federally endangered invertebrate, is found. The dragonfly's larvae require ephemeral cool springs for development. As waters within their current distribution warm or increased rainfall prolongs wet conditions, the species may go extinct.

Reduced Snow and Ice Cover

With warmer temperatures during winter months, Wisconsin will see more of its winter precipitation falling as rain rather than snow, resulting in fewer days with snow on the landscape and ice cover on the lakes. These changes in winter precipitation will affect both plant and animal communities and will impact land and aquatic ecosystems.

Statewide, less snow cover during winter also increases opportunities for white-tailed deer to forage. More favorable conditions that provide deer with more time and land to forage will hurt native vegetation, forests and croplands.

Shorter winters will impact aquatic habitats as well. Invasive aquatic plants that respond to warm temperatures will get a head start earlier in the spring, becoming nuisances during the summer. There may come a time when Wisconsin's lakes are ice-free all winter, leading to extended growing seasons for aquatic plants and for blue-green algae, which could also lead to more frequent fish kills. We discuss shifting conditions in aquatic ecosystems in Chapter 3: *Water Resources*.

Freezing Rain

Predictions for warmer winters and more precipitation falling as rain rather than as snow suggest we will see an increase in freezing rain. While all trees and other plants face the threat of ice damage, conifer trees are particularly vulnerable. Because of their structure, with a single trunk and branches that extend from it, one break in the trunk can severely injure or kill a conifer tree. In contrast to hardwood trees, which have multiple thick stems branching from the main trunk, conifers respond poorly to breaks, which will be more prevalent when freezing-rain storms increase.

WINNERS AND LOSERS: WARM AND COLDWATER FISH

Many warmwater fish species, including several game fishes, will increase under climate warming, but overall, the increases in habitat occupied by warmwater species will be much less than the losses in habitat by coldwater and coolwater species. Scientists in the Coldwater Fisheries Working Group modeled the responses of 50 common stream fishes to three different climate change scenarios. Twenty-three species (all three coldwater species, all 16 coolwater species, and four of the warmwater species) were predicted to decline, with one coldwater and four coolwater species projected to vanish from the state's streams and rivers under a worst-case scenario, four warmwater species predicted to show essentially no change, and 23 warmwater species predicted to increase. According to the projections, the same number of species increased as decreased. Warmwater game fishes expected to increase are channel catfish, smallmouth bass, largemouth bass, and black crappie.

However, the average length of stream habitat lost by the 23 declining species was more than 20,000 kilometers per species, whereas the average amount of stream habitat gained by the 23 increasing species was only about 6,800 kilometers per species, again under the worst-case scenario. The declining species decreased by approximately three times more than the gaining species increased. Specific examples for game fishes, under the worst-case scenario, include:

Coldwater Brown Trout
losing about 33,000 km of habitat (-88 percent)

Brook Trout
losing about 29,000 km (-100 percent)

Coolwater Northern Pike
losing 11,000 km (-72 percent)

Walleye
losing 4,000 km (-88 percent)

Whereas:

Warmwater Channel Catfish
gaining 1,600 km (+32 percent)

Largemouth Bass
gaining 7,000 km (+34 percent)

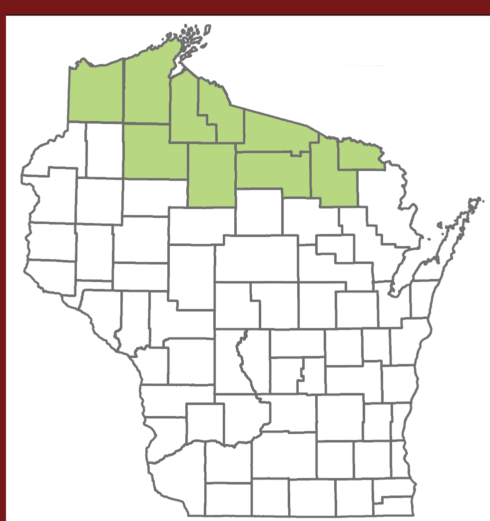
Most of the losses of cold and coolwater species will be in smaller streams that are now cold or cool but will become warm under climate warming. The gains for warmwater game fishes will occur in the relatively few medium-to-large cold and cool streams that will become warmer as climate continues to change. However, smaller trout streams, which are the vast majority of the state's trout waters, will not see lost trout being replaced by warmwater game fish. These streams may see some replacement by warmwater nongame species (various minnows and darters), but even then the replacement will be incomplete because dams and other barriers will prevent these warmwater nongame fishes from colonizing many of the new warmwater habitats created by climate warming.

THE AMERICAN MARTEN:
IMPACTS ON AN ENDANGERED MAMMAL IN WISCONSIN

The American marten is a small, carnivorous member of the weasel family. The marten was common in Wisconsin's northern forests until an intense period of timber harvest and trapping led to extirpation of the species from our state in 1939. Since the 1950s, the marten has been the subject of multiple reintroduction efforts, but despite those efforts, the marten was listed as endangered in the state in 1972. The few martens in Wisconsin currently live in the mature forests of Douglas, Bayfield, Ashland, Sawyer, Iron, Price, Vilas, Oneida, Florence and Forest counties.

Photo: Jim Woodford

The marten's low tolerance of snow-free conditions makes this species a good case study for climate change impacts. In the winters, it relies on areas underneath the snow for protection from extreme winter temperatures. Martens cannot survive Wisconsin winters without this thermal protection because their lean bodies have very minimal fat reserves for energy. Projected climate change in Wisconsin threatens to bring warming winter temperatures and more precipitation in the form of rain. Warmer temperatures mean more thawing and refreezing of the snow pack, which increases the density of the snow, and denser snow provides less thermal insulation for the marten. Snow cover is also expected to disappear earlier, exposing the marten to cold-weather conditions in the spring. The temperature, snow depth and snow density all influence the temperature of the subsurface areas that martens rely on, putting them in danger of death from energetic stress due to cold exposure.



Range of American marten.

The marten faces additional challenges as well. Rodents and other small mammals, the marten's food source, also rely on areas under the snow for protection from winter temperatures. Just like the marten, its prey will likely be threatened as the climate changes. Declines in the small mammal community will result in related declines in the marten population. This problem will be compounded by the fact that the marten's primary competitor, the fisher, hunts for the same small mammals. Climate change may lead to heightened competition between the two for resources, bringing negative impacts to both species. At this time, the long-term outlook for American martens in Wisconsin is uncertain and more research is needed to understand if and how we can preserve the Wisconsin population as the climate changes.

Reduced Soil Moisture

A warmer climate will likely result in a reduction of soil moisture. Hotter days – and more of them – will mean more evaporation and transpiration, and this includes water in the soil. Changes in soil moisture will affect plants, animals, and stream hydrology and habitats.

Drier soils can reduce the vigor of plants and their overall vitality. Trees and other plants require moisture to regenerate, and less moisture will make it more difficult for many plants to replace damaged cells.


Photo: Callen Harty

Forests such as the conifer lowlands, which are wet, boggy areas dominated by trees like tamaracks, black spruce and white cedar, depend on very moist soils. A reduction in soil moisture threatens the integrity of these forests and would lead to dead trees or even a gradual shift in the types of plants that grow in these regions.

Wildlife also will be affected by a reduction in soil moisture. Amphibians such as the American toad and eastern tiger salamander rely on humidity and moisture in the soil to maintain the water balance in their bodies. In warm, dry weather, they burrow underground to prevent dehydration. If soils dry out, these amphibians will die, impacting the rest of the forest ecosystem because they are an important food source for birds, reptiles and small mammals. Even a minor reduction in precipitation combined with high temperatures can cause rapid water loss in amphibians, and heat and water stress result in low survival rates.

Even a minor reduction in precipitation combined with high temperatures can cause rapid water loss in amphibians.

Less moisture in the soil also means less groundwater recharge to streams. When soils have adequate moisture, some of the water that falls as rain and soaks into the ground makes its way through the soil to recharge the base flow of rivers and streams. As air temperatures rise, so will stream temperatures, threatening populations of fish and insects that require cold water for their survival. This groundwater discharge helps buffer streams against increased temperatures. With reduced soil moisture, warming stream temperatures will worsen.

Drought

Even more extreme than the impacts that accrue from reductions in soil moisture is the threat of drought. While climate predictions project an overall increase in precipitation across the state, especially in the winter and spring, climate models are less certain about what will happen in the summers. More frequent or extreme periods of localized drought could impact a variety of habitats and natural communities, including water levels in lakes and wetlands, stream temperatures, forests and grasslands.

The north central part of Wisconsin contains a high concentration of the state's inland lakes. If temperatures rise and precipitation decreases in these areas, the resulting droughts will dry out wetlands and reduce habitat and nesting success for the diverse group of birds that inhabit these areas and amphibians that require wet conditions for suitable breeding sites.

Lakes in northern Wisconsin are currently receding, and the trend is projected to continue in future years.

Suitable nesting sites are becoming increasingly inaccessible to many birds. Loons, which typically nest within three to six feet of the water's edge because adults are not well-suited for movement on land, will have trouble coping with these reconfigured shorelines if drought conditions worsen.

Drought conditions can also make trees and other plants more susceptible to pests. For example, tamaracks require moist soils and are vulnerable to summer droughts. They already experience attacks from the tamarack bark beetle, but an increase in stress from droughts could reduce the trees' resilience, leaving them with little energy to combat the beetle.

While many trees and other plants will struggle to survive if drought conditions occur or persist, other species will fare better. For example, in northern Wisconsin, where drought conditions have persisted for about seven years through 2009, the rare native Fassett's locoweed is thriving. Some of these plant populations have exploded and seem – at least in the short term – to be benefiting from the dry conditions.

Flooding

While climate projections show a modest increase in precipitation across most of the state, they also include an increase in the magnitude and frequency of intense rainfall. More heavy downpours would increase the likelihood of flooding, which can damage or destroy habitats both in and outside of floodplains, essentially reestablishing floodplain boundaries. Soil conditions, the presence or absence of frost on the ground and land use affect the degree to which rainfall runs off or is absorbed into the soil, determining the extent of flooding.

After an intense rainfall event, streams and rivers often flood, saturating soils in the floodplain. Trees that grow in these areas, such as river-bottom hardwood trees including river birch and ash, cannot tolerate the saturated soils that come with prolonged flooding, and invasive plants such as reed canary grass grow in their place. Flooding also adds sediment, which covers struggling tree seedlings that cannot compete with the hardy canary grass.

Flooding could benefit other plant and animal species. Stinging nettles do well in floodplain forests, and if flooding results in new gaps in the forest canopy, vines like poison ivy, Virginia creeper and grapes will benefit. Annual native plants such as giant ragweed and jewelweed also respond well to flooding.

As for animals, trout can benefit indirectly from flooding, as they did after the floods of 2007 and 2008 in the Driftless Area. The heavy rainfall increased the base flow of many trout streams, creating a more suitable habitat for the fish. Amphibians, turtles and birds may also indirectly benefit from flooding if shallow depressions near streams capture water during floods or rain events, providing suitable habitat conditions for these species.

Species that inhabit both wetlands and grasslands are also vulnerable to flooding. In wetlands, increased flooding puts the fragile nests and habitats of many water birds at risk, and in grasslands, young birds such as the greater prairie chicken are very sensitive to rainfall and temperatures early in life because increases in heavy storms during the nesting season may chill or drown young birds.

Changing Lake Levels

As we discussed in Chapter 3: *Water Resources*, lake levels vary dramatically based on lake type and changes in precipitation and evapotranspiration. Higher temperatures and briefer periods of ice cover will result in more evaporation from lakes. Regional differences in soil type and land cover also will affect how climate changes translate into changes in lake levels.

Whether lake levels go up or down, the changes will affect components of aquatic habitats including plants, bottom materials like rock, sand or muck and coarse woody debris. Shallow lake systems will be most affected by lowered water levels, as would be the littoral zones – the areas extending from high water marks to a depth where light becomes limiting to rooted aquatic vegetation – of deep lakes.

Low lake levels leave important fish habitat, such as emergent vegetation and downed trees, out of the water along the shoreline. Human disturbance and removal of this habitat during times of low water could lead to permanent changes in ecosystem functioning. In contrast, high water conditions could result in redistribution of bottom materials and structural features to deeper water and could also uproot vegetation.

WHITE-TAILED DEER

The white-tailed deer is Wisconsin's official state wildlife animal and is the subject of an extensive harvest management program. Wisconsin deer hunting contributes $482 million annually to the state economy; conversely, large deer herds may damage crops and native vegetation by overgrazing, resulting in tens of millions of dollars in damage and alteration of native ecosystems. Given its influence on the local economy and native ecosystems, it is important to consider how a changing climate will influence Wisconsin's deer population.

As with many other species, winter survival for the white-tailed deer is a challenge. Extreme winter temperatures and snow depths are strongly associated with deer survival in northern forested regions of the state. Cold temperatures and deep snow lead to serious physical stress in deer because they must use a great deal of energy to keep warm and find substantial food in the snow. The result of such conditions can lead to high death rates in deer populations. By mid-century, the projected winter warming in Wisconsin (5-7° F in the southeast and 6-8° F in the northwest) will reduce this source of mortality in deer populations. Although winter precipitation will increase slightly by mid-century, more will be in the form of rain. More rain and warmer winter temperatures will reduce the duration of snow cover. Therefore, white-tailed deer will conserve energy and have easier access to food in Wisconsin's future climate, making winter survival much more likely. As deer abundance increases, wildlife managers will need to consider these changes in weather-related mortality and the potential impacts of larger deer herds on croplands, forests and native vegetation, especially in northern Wisconsin.

Photo: John Kubisiak, Sr.

It is also important to note that white-tailed deer populations may be exposed to more diseases as a result of changing temperature and precipitation patterns. For example, epizootic hemorrhagic disease (EHD) is an infectious viral disease common in white-tailed deer. The virus is transmitted by biting midges, primarily in late summer and early fall. Higher temperatures in winter and summer and lower precipitation in summer favor midge populations. These conditions match the future projections for Wisconsin's climate and it is reasonable to expect an increase in the frequency and/or severity of EHD. Wildlife managers will also need to consider the impacts of potential increases in disease outbreaks for white-tailed deer as a result of Wisconsin's changing climate.

Impacts and Vulnerabilities

Natural habitat conditions have never been static; rather, they change subtly over time, and the plant and animal species that inhabit them have evolved as conditions shift. But climate conditions are changing much more rapidly than in the past, and some species will struggle with adaptation at the current and projected future rates of change. Some species will have an easier time and will adapt to, and even benefit from, changes in their habitats. Others, however, will become increasingly vulnerable as they find their well-being and survival threatened by the responses of their habitat to climate change.

Edge of Range

Many native plant species in Wisconsin are at the edges of their continental distribution ranges. The northern part of the state has many plant species that are at the southern edge of their range, including those associated with boreal forest ecosystems. If temperatures continue to rise, the range of plant species currently growing in northern Wisconsin will shift northward out of the state, and the range of plants currently growing in states south of the border will expand into southern Wisconsin.

Many native plant species in Wisconsin are at the edges of their continental distribution ranges.

A warming climate will reduce suitable growing conditions for boreal forest species in Wisconsin. Birds and invertebrates within this ecosystem will be forced north, followed by tree and plant species. For example, by the end of the century, trees such as black spruce, balsam fir and paper birch will find their suitable remnant habitat in northern Minnesota or the upper peninsula of Michigan instead of Wisconsin. In addition, some boreal conifers host a species of lichen that grows only on those particular trees. If these conifers disappear from northern Wisconsin because of warming temperatures, so will the lichen, an important component of forest biodiversity. Tamarack lowlands are particularly at risk because they persist at the southern extent of their range and are sensitive to reductions in snow cover, which can allow the root systems to freeze without the insulating effects of the snow. However, some trees and other plants will benefit from warmer weather. Hardwood trees typical of the Midwest, such as hickory and black oak, will be winners in a warmer Wisconsin, expanding their range within the state as temperatures rise. There are also fish and wildlife living on the edge of their ranges. Wisconsin is at the southern edge of the national distribution of the native coldwater fish, brook trout. Where brook trout do occur south of Wisconsin, they do so in headwater streams. If their range shifts north as projected in response to rising air and stream temperatures, Wisconsin will lose most of its populations of brook trout.

Distribution range*: The spatial arrangement of plant or animal species across the landscape.*

Changing Fire Regimes

Climate influences fire regimes in two ways: directly, by affecting weather patterns such as droughts, which are conducive to fire ignition and spread; and indirectly, by causing shifts in plant communities through temperature and precipitation changes that favor or discourage fire-adapted plant species. Changes in fire regime may be most apparent for the most fire-prone natural communities, particularly in landscapes that are not fragmented, such as the jack pine-dominated barrens in central and northwestern Wisconsin. Some





CLIMATE CHANGE AND THE WOOD FROG

The wood frog is a small amphibian that is widely distributed across the northeastern U.S. and Canada, including most of Wisconsin. It can endure winter in the coldest regions of the continent because it has a unique survival skill: it can freeze in winter and thaw when spring arrives. However, the lowest temperature wood frogs can endure is about 21º F, so they rely on soil burrows, leaf litter, and snow cover to buffer their bodies from Wisconsin's extremely cold winter temperatures. Once spring arrives, wood frogs also need temporary ponds close to woodlands in order to breed. Because of predation by fish, wood frogs are rarely found in permanent water bodies.

Climate conditions are critical to the wood frog's survival. In winter, snow cover provides thermal insulation from Wisconsin's cold temperatures. In summer, moist soils and leaf litter protect against rapid water loss, and temporary ponds provide suitable breeding sites. Given the frog's reliance on these conditions for survival, ecologists expect that projected climate changes will result in substantial impacts on the Wisconsin wood frog population, both in terms of where the frogs will be found and how many will survive.

Photo: Dan Nedrelo

Survival of juvenile wood frogs to reproduction age (about 2 years old) is the most important factor regulating the size of a population. A major cause of juvenile mortality is deep freezing when the frogs are exposed to extremely cold temperatures beyond their tolerance level. The projected reductions in snow cover for Wisconsin will put wood frogs at greater risk of dying from freezing before they are able to reproduce.

Another threat to wood frogs is water loss in hot, dry conditions. Under future climate scenarios, drought conditions are projected to increase in frequency, severity, and spatial extent around the globe, which will bring serious ramifications for amphibians. Wood frogs rarely travel more than a mile; therefore, they cannot move away from widespread drought conditions such as those northern Wisconsin has experienced in recent years. Wood frogs in this region of the state suffer from a high probability of death from water loss, particularly in hot summers. Drought conditions can also affect the number and condition of breeding sites for wood frogs. With changes in water levels from the predicted increased variability of precipitation, wood frogs will face more challenges in finding suitable breeding areas and will be unable to reproduce successfully. Moreover, under prolonged high temperatures there may be mass mortality of wood frog embryos.

In addition to reduced snow cover and drought, disease is an important consideration for amphibian populations, especially because changes in temperature may increase the prevalence and incidence of numerous amphibian diseases. For example, the growth of chytrid fungus, the pathogen associated with global extinction of some amphibian species, is regulated by temperature and moisture.

The wood frog is clearly vulnerable to our changing climate in a variety of ways. Accurate predictions for future populations of Wisconsin's wood frog require careful consideration of these and other factors likely to influence their survival and reproduction.

disturbance-dependent communities such as grasslands, sedge meadows, savannas, and barrens may benefit from more numerous fires, while other natural communities will fare worse.

Pollination Disruption

While some plants are pollinated by either wind or water, insects pollinate many other plants. These plants depend on their pollinators for survival. Changes in the timing of flowering caused by early spring temperatures may disrupt that relationship or eliminate those mutually beneficial interactions. For example, some spring flowers are opening earlier than in the past, when the flies and bees that pollinate them may not yet be present. In the southern upland forests, the suite of ephemeral herbs growing on the forest floor is likely to be moderately to highly affected by climate change because of interference in pollination. These herbs bloom and drop their seeds before the forest canopy has formed its leaves. They have a very short window for reproduction, and changes in the timing of pollination caused by changes in climate may adversely affect these species.

For specialist pollinators that are associated with certain plants, these relationships can be highly vulnerable to disruptions and can even present the threat of extinction. For example, the eastern prairie fringed orchid has only one known group of pollinators – the sphinx moths. If this endangered orchid blooms early and the moth is not on a similar life-cycle schedule, the pair will come uncoupled, making pollination unlikely.


Photo: Thomas A. Meyer

Shifting Species Composition

Warmer, wetter springs may affect some habitats more dramatically than others. For example, ice is melting off the lakes earlier, which means there is a longer growing season for algae, including toxic blue-green algae. The extent of wetlands may increase with wetter springs, but there may also be a shift to wetter, deeper wetland types associated with high water. Transitional wetlands that are more dependent on groundwater may decrease or be restricted to smaller areas because of increased evapotranspiration. Aquatic plant species that are adapted to cooler water temperatures may become scarce as temperatures rise.

When the temperature of a lake's water rises, there is a greater likelihood that species composition within the lake will shift. Increased temperatures may change the algal composition of the lake entirely, and increased algal growth reduces light penetration and clarity, making it more difficult for loons and other sight-feeding birds to locate food and for rooted aquatic plants to grow.

Higher water temperatures may also lead to increased blue-green algae growth. The algae deplete the lake's oxygen, resulting in dead zones. Some species of toxic blue-green algae can impair a water body, sickening swimmers, livestock or pets. An increase in nuisance levels of blue-green algae growth is more likely to occur in shallow, nutrient-rich lakes, many of which are found in the southern and southeastern parts of the state. A more thorough discussion of climate impacts on Wisconsin's water resources is presented in Chapter 3.

Species Mobility

The increased rate of climate change makes adaptation challenging for plants and natural communities that disperse their seeds over short distances. While plants with light, wind-spread seeds, such as orchids and asters, or those that are propagated by spores, such as ferns, mosses and lichens, may have a less challenging time keeping up with the rate of climate change, trees and other plants with larger, heavier seeds can take much longer to disperse. In some cases, the rate of climate change may exceed the rate at which species can disperse, and plant species with poor mobility – unable to expand northward to more suitable habitat – will die out.

***Dispersal**: The natural distribution of plant seeds and the offspring of organisms away from their area of origin or from centers of high population density over a wide area by various methods.*

Some wildlife species move across the landscape more easily than others. Although more mobile species can travel to more suitable climatic conditions, this is not an option for the eastern red-backed salamander. This species is considered a poor disperser. Because it is sensitive to water loss from exertion and exposure, its dispersal range is restricted to less than one mile. This situation poses a challenge to local populations. The eastern red-backed salamander must have viable habitat within that one mile in order to survive. Yet projected climate changes suggest that this salamander may be unable to colonize within a suitable climate niche, which can lead to local extinction. This fate is not unique to the eastern red-backed salamander; rather, it will be shared by many amphibian species and other poor dispersers.

Photo: Elizabeth Katt-Reinders

WILDLIFE RESPONSES TO CLIMATE CHANGE

SPECIES THAT MAY BENEFIT	SPECIES THAT MAY BE HARMED
CHARACTERISTICS	
Short generation times	Long generation times
Wide distributions	Narrow/restricted distributions
Move easily across landscape	Poor dispersal ability
Habitat generalists	Habitat specialists
Not sensitive to human activity	Sensitive to human activity
EXAMPLES	
Gray squirrel	American marten
White-tailed deer	Red-backed salamander
European starling	Spruce grouse
Canada goose	Common loon

Non-Climate Stressors

It is important to note that there are also nonclimate stressors that threaten biodiversity and habitat. These include habitat loss and fragmentation, invasive species and pollution. Climate change will interact with and exacerbate these stressors, intensifying and amplifying the challenges they pose to natural habitats and biodiversity.

Fragmentation and Habitat Loss

Fragmentation is the disruption of contiguous natural habitats into a patchwork of isolated natural areas surrounded by landscapes that are inhospitable to native vegetation and wildlife. Urbanization, land development and conversion of natural habitats to agricultural uses has broken up ecosystems so that there is no corridor or connected pathway through which they can travel. Plants and animals seeking to disperse and migrate to more suitable habitats as a result of climate change face the challenges of fragmented habitats and poor connectivity of suitable ecosystems. Fragmentation not only threatens the survival of animal populations but also impacts plant communities and their component species.

The combination of climate change and increased fragmentation is likely to affect species and natural communities statewide, both directly and through cascading effects. Many habitats in the southern portion of the state are already fragmented, leaving natural plant communities in that region more vulnerable to climate change. Forests and wetlands in the north and along the Great Lakes may be impacted to a lesser extent because of the presence of continuous habitat.

Fragmentation poses major challenges for plants dispersing their seeds. Species groups with poor dispersal abilities are expected to be more affected by rapid climate change than those that have the ability to migrate or disperse to suitable habitat. Long-distance seed dispersal is a rare but important occurrence that allows these fragmented species to maintain their populations, strengthening their resilience in the face of habitat disruption, climate change and other threats. Species that are able to disperse over long distance have an advantage over those that cannot as climate conditions shift habitat conditions, threatening fragmented habitats. Some groups of species, such as those with light or animal-dispersed seeds, may be better able to overcome the effects of fragmentation by colonizing scattered patches of suitable habitat via long distance dispersal. Often, however, these are weedy or invasive native and non-native species.

Invasive Species

Invasive species will have more opportunities to expand within or move into Wisconsin landscapes as climate change provides habitat conditions conducive to many of these species. Warmer winter temperatures may allow invasive species that are already established in southern and western Wisconsin to expand their ranges north. Species that lie to the south or west of the state border may invade and become established, bringing with them disease-causing organisms.

Climate change can promote the spread of invasive species in a number of ways. During flooding events, water bodies can become interconnected, allowing invasive species to spread from one lake to another. Wetter summers may reduce the effectiveness of purple loosestrife biological control organisms (weevils and leaf-eating beetles) in many wetlands, especially in kettle topography. Change in phenologies will require change in the timing of control efforts for this invader. In contrast, drought may open up new habitat that is well-suited for an invasive species.

Species not native to the area will be more likely to survive when temperatures rise because many species, such as kudzu, *Hydrilla*, water hyacinth or the red swamp crayfish, will be able to overwinter. These species are well-established in the southern United States and have been limited in Wisconsin by cold temperatures and ice cover. Recently, however, they have been found overwintering in small constructed ponds.

Native species*: Species that naturally occur within the community type; endemic to the area.*

Invasive species*: Species capable of rapid reproduction and spatial expansion, which may displace more specialized native species and/or are difficult to eradicate. Invasive species are of particular ecological concern if they are exotic, or introduced, to the area in question.*

Pollution

Regardless of climate change, pollution weakens the resilience of natural habitats. As climate change brings heavier rainfalls, polluted runoff from stormwater will increase, threatening ecosystem health. Runoff transports sediment, nutrients and chemicals from agriculture, industry and urban areas through our watersheds and natural habitats, polluting our waterways, wetlands and landscapes. If the projected increase in the magnitude and frequency of heavy rains occurs, we can expect to see the problem of polluted runoff worsen, increasing the threats to the health and vitality of Wisconsin's habitats and the species that inhabit them. Please see Chapter 3: *Water Resources* for a more in-depth discussion of stormwater runoff and water quality.

Photo: Andy Clark

Adaptation Strategies

The wide variety of natural habitats in Wisconsin and the biodiversity of the plant and animal species that inhabit them result in a wide range in the responses of species to climate change impacts. The variety of possible strategies for adaptation reflects the breadth and depth of climate impacts and vulnerabilities. In keeping with the organizational framework presented in Chapter 2: *Understanding Adaptation*, we present here several adaptation strategies relevant to Wisconsin's natural habitats and biodiversity. (Please see the Coldwater Fisheries, Forestry, Plants and Natural Communities, Water Resources and Wildlife Working Group reports at www.wicci.wisc.edu for a more detailed discussion of adaptation strategies.)

ADAPTATION

TAKING ACTION

Through proper stewardship, protected habitats can be maintained to promote the highest levels of natural resilience to change. The following principles are best practices for the goal of stewardship for ecological resilience:

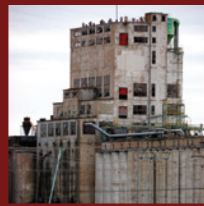
Adaptive Management

- **Slow, managed change will be an important tool in helping managers cope with changing forest conditions. Forest managers already use a number of tools, policies and practices to ensure that the forests of Wisconsin are sustained into the future. These forest management tools and policies (such as invasive species management and assisted regeneration) can be valuable in reducing climate change impacts.**
- **Implement coastal and aquatic ecosystem management systems such as ecological buffer zones, open space preservation and conservation, ecosystem protection and maintenance, ecosystem restoration, creation, and enhancement, and aquatic invasive species management to support natural resilience.**
- **Utilize best management practices on agricultural lands, for example, implementing conservation tillage approaches to limit surface runoff or favoring rotational grazing over continuous grazing in riparian and upland areas of watersheds.**
- **Protect environmentally sensitive agricultural lands that provide wildlife habitat and water resource protection through enrollment in the Conservation Reserve Program or similar federal or state programs.**
- **Manage riparian vegetation to promote stream bank and channel stability, reduce erosion and siltation, and protect streams from damage from high-flow events. Provide shading to maintain the lower temperatures of groundwater input over longer lengths of coldwater streams.**
- **Adopt riparian and watershed land use practices that promote infiltration of precipitation and recharge of groundwater to maintain or enhance groundwater inputs to springs, ponds, and streams. Reduce existing, or limit creation of additional, impervious surfaces in critical watersheds containing coldwater streams, and utilize best runoff management practices in urban areas. Continue enforcement of laws governing groundwater use that are critical to protecting coldwater streams and trout fisheries from climate change.**
- **Manage fish population age structure to create resilience for interdecadal water level variability; determine minimum number of age classes needed for resilience.**

Managing Cumulative and Synergistic Threats

- **Northern Pike Fishery: Continue closed season for northern pike on tributary streams and daily bag limits; restore stream channels; manage**




STRATEGIES

dam removal; manage water levels at restoration sites; continue emphasis on wetland acquisition, stream habitat and wetland restoration.

- Lake Sturgeon Fishery: Continue restricted harvest; ensure availability of spawning sites at dams under high- and low-water conditions through FERC licensing; protect hydrologic integrity of watershed of small rivers to maintain genetic diversity; reduce runoff of suspended solids; provide in-stream habitat improvement where possible and at critical sites.
- Wetland Habitat: Protect and restore integrity of wetland hydrologic regimes; consider seed bank manipulation to counter *Phragmites* invasions of exposed lakebed; control polluted runoff through pollutant load limits and runoff best management practices (particularly stream bank buffers); consider woody vegetation for stream buffers; protect sites by acquisition or conservation easement; evaluate existing conservation properties in a local and landscape context.

Approximating Natural Disturbance Regimes

- Establish and maintain corridors of contiguous habitat along natural environmental continuums to provide for migration and favorable conditions for local adaptation. An analysis of connectivity at landscape levels can identify important long-term opportunities for conservation actions.
- Assisted migration (relocating plants and animals geographically in anticipation of the projected climate change), while controversial, has the potential to facilitate long-term species survival.
- Restore prior-converted wetlands in upland agricultural areas to provide flood storage and runoff filtration, mitigating storm flows and nutrient loading downstream.
- Enhance and restore shoreline habitat (for example, coarse woody littoral and riparian vegetation or bio-engineered erosion control) to withstand variations in water levels.

BUILDING CAPACITY

- Use temperature and fish models to evaluate streams and their watersheds. Identify cold-water resources for protection and restoration, and allow for the evaluation of potential responses to climate change scenarios so that managers can make informed decisions when allocating management resources.
- Northern Pike Fishery: Examine zoning regulations for adequacy in protecting hydrologic integrity of both surface and groundwater of west Green Bay coastal zone.
- Lake Sturgeon Fishery: Develop innovations for passing fish upstream without passage of aquatic invasive species; develop census techniques for sturgeon ranging from juveniles to 10 years old.

(Adaptation Strategies continued)

- Use a triage approach to protecting coldwater streams from the impacts of climate change by setting realistic management expectations for success and evaluating possible climate change impacts on different coldwater streams. Use stream restoration techniques that promote colder water temperatures (for example, narrowing and deepening channels), and target restoration efforts to streams most likely to realize these benefits under a changing climate.
- Establish monitoring sites for forest ecosystems. These complex communities are most likely to see climate change impacts and will provide the means to track the rate of change, including changes in wildlife species, trees, shrubs and herbs.
- Wetland Habitat: Examine policies and regulations protecting lands below the ordinary high-water mark; policies need to be preemptive to protect. Identify, map, and prioritize potentially restorable wetlands in floodplain areas.

COMMUNICATING

- Build a stronger relationship with the public to establish a critical mass of ecological knowledge in the community. Assemble oral histories, photos, records, and studies to document previous conditions and present them to the public.
- Conduct a public review of state waterways and wetland regulation for adequacy in protecting coastal wetlands under a changing climate and in removing or modifying dams to allow for fish passage in response to changing stream conditions.
- Share results of vulnerability assessments and adaptive management strategies with other resource managers.
- Educate about the benefits of pollution load limits (total maximum daily loads, or TMDL) for reducing phosphorus and total suspended solids.

Photo: William Walker

Photo: Callen Harty

FILLING GAPS

- To reduce the amount of uncertainty in making decisions about resource allocations, conduct risk assessments of resource vulnerability to changing environmental conditions based on climate projections for individual species and natural communities. The assessments should be used in prioritizing management and other adaptation actions.
- Use climate analog models to identify other landscapes that currently have temperature and precipitation patterns similar to what Wisconsin's forests could experience in the future. Study the forest composition, disturbance, and pest and disease interactions of these sites to determine how Wisconsin's forests may respond in the future.
- Collect stream monitoring data (water temperature, flow, and fish abundance) to test predictions of the effects of climate change on the distribution of coldwater fish in streams and to determine how changes in air temperature and precipitation effect changes in stream temperature and groundwater input to streams.
- Increase the certainty of long-term precipitation and temperature trends and patterns to help forest modelers simulate climate-related changes in forests.
- For the Northern Pike Fishery: Assess the effect of lost submergent aquatic vegetation on predation and juvenile mortality; define relations between nutrient loading, water quality and sustainable spawning; determine the restoration potential of macrophyte habitat for juveniles.
- For the Lake Sturgeon Fishery: Assess the significance of egg predation on population; assess the success of downstream migrants passing over dams.
- Inventory wetland habitat fragmentation and connectedness and identify critical habitat for protection; assess the effectiveness of carp population control measures in protecting aquatic habitat.

Source material for this chapter was drawn from the Coldwater Fish and Fisheries, Forestry, Plants and Natural Communities and Wildlife Working Group reports, available online at www.wicci.wisc.edu.

Conclusion

Climate change is already impacting and will continue to impact natural habitats and communities. The current and projected rate of climate change is at least as rapid as past rates, and in many instances it exceeds the abilities of species to adapt. Some species will benefit at the expense of others, and natural resource managers and other stakeholders will need to determine their priorities to further develop robust adaptation strategies. Natural communities and ecosystems with greater biodiversity will fare better in the face of climate change than more homogenous ecosystems, and we will need to increase the resilience of ecosystems within structures that exist while enhancing our knowledge of climate change impacts.

CHAPTER FIVE

AGRICULTURE AND

Agriculture in Wisconsin

Impacts and Vulnerabilities

Adaptation Strategies

Photo: Wisconsin Department of Natural Resources

THE SOIL RESOURCE

Agriculture is an essential component of Wisconsin's economy, identity and culture. The Dairy State is one of the nation's most diverse agricultural producers, generating more than $59 billion in economic activity on 36 percent of the land in the state. The combination of a suitable climate and fertile soils allows farming to be one of the mainstays of the Wisconsin economy. With a new focus on producing renewable energy crops, our agricultural land base will become even more valuable.

Climate change is impacting many facets of agriculture in Wisconsin, and future changes are likely to continue. This report is our first assessment of climate change impacts on Wisconsin agriculture, and our analysis is preliminary. Drawing on research available at the time of this report's production, we focus on climate impacts on corn and soybean yields. Climate change also has the potential to degrade the soil resource on which all Wisconsin agriculture is ultimately based. Additionally, agricultural activities can increase the loss of soil and associated nutrients to water resources, with implications for aquatic ecology.

A significant question confronting agriculture concerns the ways in which cropping systems and farmers have responded to recent changes in climate and whether future climate change and increasing levels of carbon dioxide in the atmosphere will significantly increase the risk of failure for agro-ecosystems. Climate change poses real threats to the stability of agro-ecosystems in the long term, potentially jeopardizing food and economic security. Numerous studies have demonstrated the sensitivity of cropping systems to climate; however, no consensus has yet emerged regarding the specific mechanisms responsible for causing such sensitivities or how these play out in specific geographical regions.

Agriculture in Wisconsin

Importance of Agriculture to Wisconsin

The economic impact of agriculture in Wisconsin is substantial. Agriculture contributes more than 350,000 jobs to the Wisconsin economy, or 10 percent of total employment. Agriculture provides a diversity of ecosystem goods and services that enhance the economy and improve the quality of life in our state. Our agricultural systems use more than 15 million of the 42 million acres of land in the state (figure 1), although the average size of our 78,000 farms is a modest 194 acres. Approximately two-thirds of the dollars generated by Wisconsin agriculture comes from livestock, dairy and poultry. Crops such as corn and soybeans, vegetables and horticultural crops make up much of the remainder.

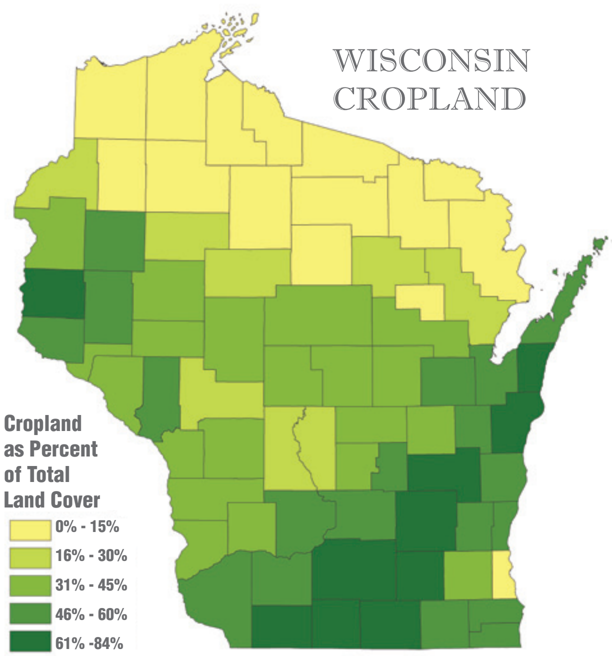


Figure 1. Percent of total land cover in each county classified as cropland.

The Dairy State ranks first nationally in cheese production and second in milk and butter production. Wisconsin is also second in oats, carrots and sweet corn. It remains the national leader in processed snap beans, cranberries, corn for silage, mink pelts and milk goats. It is also among the top five states for commodities such as potatoes, maple syrup, mint oil and cucumbers for pickles. Furthermore, Wisconsin is ninth in trout aquaculture, corn for grain and fresh market cabbage. Other agricultural products, such as cherries, ginseng, Christmas trees and pumpkins, help define rural Wisconsin, as do an increasing number of award-winning craft cheeses and beers.

In addition, agriculture supports a growing bioeconomy as part of our quest for more homegrown renewable energy resources. Growth in bioenergy will make it more important that we understand the impacts of climate change on agriculture. Biomass crops can be used to produce ethanol and other fuels, thereby decreasing our dependence on imported fossil fuels. By protecting agricultural resources, we also provide food security for the future by producing nutrition and fiber for humans and animals.

Geographic and Geological Diversity

The diversity of the social and economic characteristics of Wisconsin agriculture is matched by the diversity of the physical setting in which they occur. The south central part of Wisconsin is characterized by gently sloping ground moraines, lake plains, outwash plains, drumlin fields, end moraines, flood plains, swamps and marshes. The soils are derived from glacial drift and are generally very deep, well-drained and loamy. The majority of this area is in cropland with a large proportion in cash grains.

Source: Map created by Dan McFarlane. Summer 2010. Wisconsin Land Use Megatrends: Agriculture. Center for Land Use Education. Data from U.S. Department of Agriculture, National Agricultural Statistics Service. 2009 Cropland Data Layer.

Immediately to the north are the Central Sands. This area, approximately 3,400 square miles in size, is characterized by outwash till and glacial sand from the most recent period of Wisconsin glaciation. Almost half of the area was once covered by Glacial Lake Wisconsin. Much of this area is now forested and provides both lumber and pulp production, with much of the rest used mainly for cash-grain crops, dairy farms, livestock grazing, irrigated vegetables, Christmas trees or cranberries.

To the west of this region is the Driftless Area. The geology is characterized by both sandstone and dolomite outcrops that create a complex scenic landscape. Most of the land is in agriculture, with woodlots on the steeper slopes and cropland in the valley floors and on ridge tops.

The eastern area of Wisconsin bordering Lake Michigan is characterized by nearly level to rolling till plains, lake plains and outwash plains mixed with drumlin fields, bedrock-controlled moraines, lake terraces, dunes, swamps and marshes. Much of the area is dominated by land uses dedicated to cash grains and pasture.

Each of these different biophysical and ecological regions of Wisconsin relies on different techniques and management strategies to produce the commodities and products listed earlier. Wisconsin farmers have adjusted their production strategies to the often-unique agro-ecological areas of the state where they farm and to the normal – and often extreme – variability in Wisconsin weather. This long-standing experience with adaptation will assist farmers in formulating responses to climate change; however, uniform statewide strategies are unlikely given the diversity of agricultural systems, geography and other conditions described in this chapter.

SOIL AND LANDFORM TERMINOLOGY

Dolomite: a sedimentary carbonate rock composed of calcium magnesium carbonate; limestone that is partially replaced by dolomite is referred to as dolomitic limestone.

Drumlin: an elongated hill formed by glacial ice pushing underlying till into mounds. Its long axis is parallel with the movement of the ice, with the blunter end facing into the glacial movement.

Flood plain: flat land adjacent to a stream or river that experiences occasional or periodic flooding, usually during periods of heavy precipitation.

Glacial drift: gravel, sand or clay transported and deposited by a glacier or by glacial meltwater.

Lake plain: a former lake bottom, usually a featureless surface that formed from the deposition of sediments carried into the lake by streams.

Lake terrace: a level plain, usually with a steep front, bordering a lake.

Loam: an ideal agricultural soil composed of sand, silt, and clay; typically rich in nutrients, with good water retention and drainage characteristics; relatively easy to till.

Marsh: a tract of low, wet, soft land that is temporarily or permanently covered with water, characterized by aquatic, grass-like vegetation.

Moraine: any glacially formed accumulation of unconsolidated soil and rock; typically found in areas acted upon by a past ice age.

Outwash plain: a broad, outspread flat or gently sloping deposit of material left by the water coming off a melting glacier.

Outwash till: unsorted rock and sediment left by retreating glaciers.

Swamp: a seasonally flooded bottomland with more woody plants than a marsh.

Till: unstratified soil deposited by a glacier; consists of sand and clay and gravel and boulders mixed together.

Till plain: an extensive, relatively flat area overlying a till.

Impacts and Vulnerabilities

Climate change will likely impact agriculture in a variety of ways, some negative and some positive. For this first assessment of climate impacts on agriculture, we provide three tables (tables 1,2 and 3) listing potential climate change impacts, followed by an analysis of shifting plant hardiness zones and in-depth discussions of climate impacts on corn and soybean yields and soil loss.

The impacts of climate change on Wisconsin agriculture will be both direct and indirect. Direct impacts will generally occur as changes in temperature and precipitation impact crop productivity; the timing of those changes within agricultural cycles will deter-

DIRECT IMPACTS - POSITIVE

ASPECTS OF CLIMATE CHANGE	IMPACT ON AGRICULTURAL PRODUCTION
Longer frost-free periods	Use of higher-yielding genetics
More freeze/thaw cycles in winter	Increased soil tilth and water infiltration
More summer precipitation	Reduced plant stress
More soil moisture	Reduced plant stress
Higher dew point temperatures	Reduced moisture stress
More diffuse light (increased cloudiness)	Reduced plant stress
Higher water-use efficiency	Higher yields
Warmer spring soil temperatures	Use of higher-yielding genetics
Reduced risk of late spring or early fall frosts	Use of higher-yielding genetics
Increased atmospheric CO_2 levels	Increased photosynthesis and yields

Table 1. Positive direct climate change impacts on agricultural productivity.

Photo: Elizabeth Katt-Reinders



mine the nature and severity of each impact. Indirect impacts – for example, increasing numbers of weed and pest species due to changing conditions that become more advantageous to them – are harder to predict. These can lead to additional indirect impacts such as the need to use more herbicides and pesticides, followed by environmental impacts of these increased applications, which may lead to legal or policy responses.

We hope to explore these potential impacts – both positive and negative – in greater detail in subsequent assessment reports.

DIRECT IMPACTS - NEGATIVE

ASPECTS OF CLIMATE CHANGE	IMPACT ON AGRICULTURAL PRODUCTION
More spring precipitation causes waterlogging of soils	Delayed planting, reduced yields, compaction, change to lower-yielding genetics
Higher humidity promotes disease and fungus	Yield loss, increased remediation costs
Higher nighttime temperatures in summer	Plant stress and yield loss
More intense rain events at beginning of crop cycle	Replanting and field maintenance costs; loss of soil productivity and soil carbon
More droughts	Yield loss, stress on livestock, increase in irrigation costs, increased costs to bring feed and water to livestock
More floods	Replanting costs, loss of soil productivity and soil carbon; damage to transportation infrastructure may reduce delivery to milk processing plants
More over-wintering of pests due to warmer winter low temperatures	Yield loss, increased remediation costs
More vigorous weed growth due to temperature, precipitation and CO_2 changes	Yield loss, increased remediation costs
Summertime heat stress on livestock	Productivity loss, increase in miscarriages, may restrict cows on pasture
Temperature and precipitation effects on pollinators	Losses to cropping (forage, fruits, vegetables) systems
New diseases or the re-emergence of diseases that had been eradicated or under control	Enlarged spread pattern, diffusion range, and amplification of animal diseases

Table 2. Negative direct climate change impacts on agricultural productivity.

INDIRECT IMPACTS

SITUATIONAL CHANGE	IMPACT ON WISCONSIN AGRICULTURE
Regulation involving greenhouse gas emissions	Potential increased costs to meet new regulations; opportunities to participate in new carbon markets and increase profits
Litigation from damages due to extreme events or management of carbon markets	Legal costs may increase
New weed and pest species moving into Wisconsin	Control strategies will have to be developed; increased pest management costs and crop losses
Vigorous weed growth results in increased herbicide use	Increase in resistance or reduction in time for development of resistance; regulatory compliance costs or litigation over off-site damages from pesticides
Possibility of increased inter-annual variability of weather patterns	Increased risk in crop rotation, genetic selection, and marketing decisions
Increased global demand for food production due to climate and demographic changes	New markets; increase in intensification of production; increase in absentee ownership
Increased period for forage production	Decreased need for large forage storage across winter for livestock operations
Increased taxes or regulations on energy-dependent inputs to agriculture (for example, nitrogen fertilizer)	Profitability impacts on producers; loss of small-scale farm supply dealers

Table 3. Indirect climate change impacts on agricultural productivity.

Yields

The direct impacts of climate change on crops are complex and depend on a number of interrelated conditions. In general, research suggests that warming temperatures in spring and fall would help boost agricultural production by extending the growing season across the state; however, increased warming during the core of the growing season – June through August – appears to have a negative impact on row crop production. Increases in precipitation appear to counteract the negative effects of warming temperatures within a narrow range; furthermore, climate change will have varying impacts on yields from crop to crop. In this first assessment, the Agriculture Working Group focused solely on impacts on corn and soybean yields.

Using crop yield information from Wisconsin counties combined with climate data, UW scientists determined that both corn and soybean yield trends were supported by cooler and wetter conditions during the summer because increases in precipitation seem to counteract the potentially negative impacts of recent warming on crop yield trends. Study results suggest that for every 2º F of warming, corn and soybean yields could potentially decrease by 13 percent and 16 percent, respectively. However, modest increases in precipitation during the summer could help boost yields by 5-10 percent, counteracting the negative effects of increased temperature to a limited extent.

While northern U.S. corn belt regions, including Wisconsin, may benefit from climate and management changes that lengthen the crop-growing period in spring and fall, they may not be immune to decreased productivity caused by warming during summer months if summer precipitation declines or becomes increasingly variable.

Based on historical relationships between county-level climate data and USDA crop yield information across southwestern regions of Wisconsin, corn yield variability has been most influenced by maximum temperatures and precipitation in the month of July, whereas across northeastern Wisconsin, daily high temperatures in September had the greatest impact on corn yield variability. In contrast, soybeans were most affected by precipitation in July and August over the west central and southeast regions of the state and by minimum daytime temperatures during May for northeastern counties close to Lake Michigan.

During some years from 1950 to 2006, above-normal average high temperatures during July and August – which are on the same order of magnitude projected by climate models under future warming scenarios – were correlated with annual yields 10-30 percent lower than the expected averages. Surprisingly, summers during which precipitation exceeded the average by 50-100 percent translated into yield increases of only 3-11 percent. Overall, crop yields were favored by cooler-than-average daytime high temperatures in late summer and above-normal temperatures in September.

Results from research by UW scientists, using historical data gathered across Wisconsin from 1950 to 2006, suggest that any degree of additional warming during the summer months appears to be correlated with lower-than-expected corn and soybean yields. An increase in monthly average maximum temperatures of 7º F in July and August could lead to corn yield losses of 22-28 percent and soybean yield losses of 13-24 percent if adaptive measures do not occur and precipitation does not increase. It appears that any degree of future warming during the core of the growing season would have a negative impact on productivity in the absence of adaptation.

Overall, crop yields were favored by cooler-than average daytime high temperatures in late summer and above-normal temperatures in September.

The potential responses of Wisconsin agriculture to changing climate, atmospheric composition and land management contain a great deal of uncertainty. For example, changes in the timing of precipitation paired with increased warming during the growing season may significantly alter the rate of development of corn and soybeans. Furthermore, future increases in atmospheric carbon dioxide could increase soybean production, but the effects may vary under different precipitation scenarios. Environmental changes in the future might make some watersheds more suitable for agriculture while others could be limited by drought and other extreme weather events. In order to cope with future conditions and prevent yield losses, farmers might need to adapt by adjusting the timing of planting or the genetics of the crops they choose to plant.

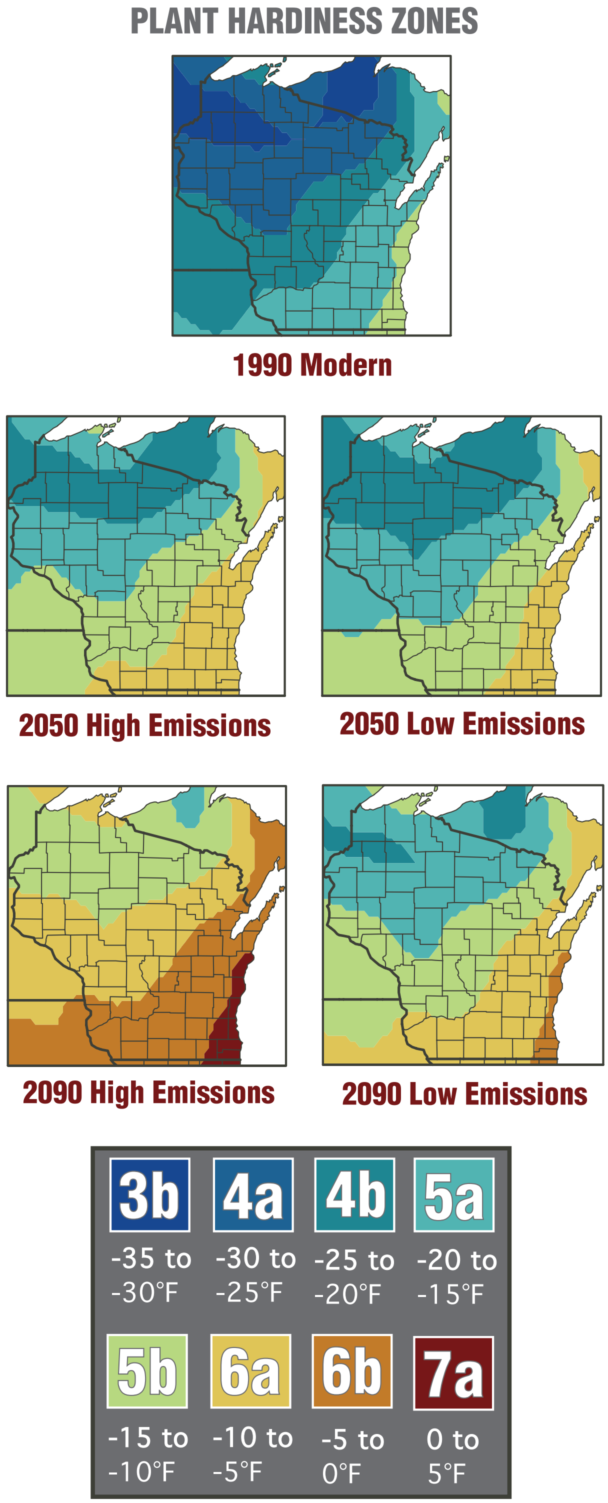

Photo: William Walker

WILL MORE CARBON DIOXIDE IN THE AIR BOOST CROP YIELDS?

PROBABLY NOT FOR CORN. While it is true that plants depend on carbon dioxide for photosynthesis, carbon dioxide levels have been rising dramatically over the last few decades, and new experimental data suggest that corn photosynthesis is already saturated at current levels in the atmosphere. Therefore, any further increases in carbon dioxide will not boost corn productivity.

MODEST INCREASES FOR SOYBEANS ARE LIKELY. In the case of soybeans, it appears that increases in yield could still occur as atmospheric carbon dioxide levels rise. But the expected yield increase is modest, and new projections are approximately 50 percent lower than previous research had projected. New studies suggest that if temperature, precipitation and soil resources remain unchanged, soybean yields may increase by approximately 13-15 percent across Wisconsin as atmospheric carbon dioxide levels climb toward 550 parts per million by 2050, compared to today's level of 388 parts per million.

SHIFTING HARDINESS ZONES



WICCI climate scientists have documented a significant expansion of Wisconsin's growing season since 1950. Climate models project an increase in temperatures that will continue to lengthen the growing season and affect crop productivity in Wisconsin. While the extension of the growing season may boost the productivity of some crops, others could see negative effects if temperatures warm too much. To help us understand how climate will influence agriculture, we can look at how plant hardiness zones are shifting with changes in climatic conditions. As these zones shift, so do the types of plants that are able to grow in varying regions of the state.

We have already seen shifts in plant hardiness zones; these will continue to move northward as the climate continues to change. The maps illustrate potentially major changes in climatic conditions that characterize Wisconsin, and by the end of the century we might be able to grow new varieties of fruit crops, but new insects and diseases that impact all of our crops may move into the region, and growers may be challenged by additional management problems that will require adaptive measures. This implies that the growth and maintenance of our state's agricultural crops, particularly the fruit industry, may require new management methods and practices to remain profitable.

Figure 2. Plant hardiness maps.

Source: Michael Notaro, David Lorenz and Daniel Vimont, Nelson Institute Center for Climatic Research, University of Wisconsin-Madison.

Soil Erosion

When soil particles erode from agricultural lands, the loss degrades the quality of the soil resource and contributes to the degradation of rivers and streams. In this section, we focus on climate change impacts on soil quantity and quality; the impact of soil erosion on Wisconsin's aquatic ecosystems is discussed in detail in Chapter 3: *Water Resources*.

Erosion degrades the soil body by removing material from the surface. The soil material at the surface is the layer most supportive of plant growth; stripping away this topmost layer is a loss of "natural capital." The creation of soil from parent materials proceeds in large measure from the top down, where plant carbon inputs are greatest and soil microbiological activity benefits from good aeration. Human-added nutrients, such as synthetic fertilizer or livestock manure, are greatest at the surface, as are nitrogen additions from legumes growing in the soil. The formation of soil structure that facilitates root growth, water infiltration and desirable water-holding capacity is typically most advanced near the surface.

A relatively small fraction and number of precipitation events each year cause most of the annual soil loss from agricultural fields.

A relatively small fraction and number of precipitation events each year cause most of the annual soil loss from agricultural fields. Annual precipitation is increasing across Wisconsin, as are the number of days with one or more inches of rainfall. The amount of rainfall during the wettest seven-day period of each year also appears to be increasing. These precipitation trends increase the opportunities for significant soil erosion.

Recent estimates by soil scientists indicate that soil erosion losses are increasing in Wisconsin, most likely because of a combination of cropping system changes, relatively erodible land being returned to cultivation and changing precipitation patterns. These influences interact, and climate change may exacerbate the current threats to soil erosion from cultivation and land use practices. In the absence of appropriate adaptation actions, future precipitation patterns could cause soil erosion in Wisconsin to double by 2050 from 1990 rates.

In the absence of appropriate adaptation actions, future precipitation patterns could cause soil erosion in Wisconsin to double by 2050 from 1990 rates.

Although farmers have known which practices are necessary to keep soil in place despite heavy rainfalls (table 4), these practices have been based on past climate scenarios. The boundaries of climate variability are shifting, and soil conservation practices will need to adapt to the precipitation changes we are seeing and expect to see in the future.

At the core of soil conservation is the voluntary adoption of appropriate practices by farmers. These include cropping and tillage practices as well as laying out fields, land shaping, and engineered structures. Federal, state and county governments provide technical assistance and cost-sharing as incentives for farmers to adopt these preferred practices; however, Wisconsin has ample room for improvement when it comes to their implementation.

SOIL CONSERVATION PRACTICES

PRACTICE	DESCRIPTION
Crop rotation	Planting a sequence of species through the years to reduce soil loss but meet farm needs
Crop residue management	Tillage practices that leave residue on top of the soil rather than bury it
Contour farming and strip-cropping	Tilling and planting across the slope, following the contours of the land, and planting crops in alternating bands of species that permit more or less erosion
Contour buffer strips	Permanently planted strips along the contoured field
Cover crops	Temporary, fast-growing species that protect the soil between main crops

Table 4. Soil conservation practices.

Adaptation Strategies

The wide range of factors that contribute to climate impacts on agriculture and soil conservation leads to a wide range of possible strategies for adaptation. In keeping with the organizational framework presented in Chapter 2: *Understanding Adaptation*, we present here several adaptation strategies relevant to Wisconsin's agricultural systems. (Please see the Adaptation and Soil Resources Working Group reports at www.wicci.wisc.edu for a more detailed discussion of adaptation strategies.)

Photo: Avery Dorland

ADAPTATION

TAKING ACTION

- **Expand the adoption of accepted soil-conserving field practices that will reduce erosion and polluted runoff to streams and lakes.**

BUILDING CAPACITY

- **Develop a stronger presence for an agro-meteorology (or agro-climatology) program within the University of Wisconsin System, including courses that would train the next generation to understand the connections between agriculture and climate.**
- **Initiate an ongoing analysis of how bioenergy policies and changing production practices influence the effectiveness of soil conservation programs.**
- **Provide the resources necessary to facilitate broad adoption of the practices we know can reduce soil erosion and to ensure compliance with existing rules.**

COMMUNICATING

- **Communicate what needs to be done within agriculture to adapt to changing climate, using basic research and a new type of framework for integrating these findings into policy decision-making.**
- **Review public policy surrounding subsidies for soil conservation practices to determine if they meet present and future needs.**
- **Expand watershed-based educational programming efforts with appropriate targeting of hydrologic units, farms and fields.**

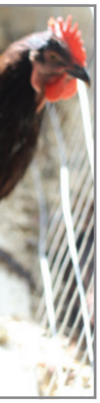


Photo: Elizabeth Katt-Reinders

Photo: Lance Klessig

Photo: William Walker

Photo: Avery Dorland

STRATEGIES

- **Apply state-of-the-art evaluation work related to soil conservation to measure impact and improve programs and practices.**

FILLING GAPS

- **Re-establish a network of agro-meteorological stations across the state of Wisconsin to collect climate observations, including estimates of evapotranspiration, to support research and development of agricultural practices.**
- **Create a program to collect on-farm information, such as fertilizer and pesticide usage, other management practices and yield responses to support researchers and educators across the state.**
- **Provide support for placed-based research that integrates ecological and social science with field work, numerical modeling, remote sensing and the social sciences to better understand how ecosystem services associated with agricultural systems can be sustained into the future.**
- **Develop new metrics for the sustainability of soil and water resources.**
- **Develop strategies to objectively and efficiently identify portions of the landscape that should be maintained in healthy full-cover perennial vegetation, and develop programs to encourage returning these areas to this condition.**
- **Undertake research to enable more inclusive accounting of the costs and benefits of soil management choices.**
- **Develop systematic, transparent and accessible monitoring programs for soil conservation and its impacts on water quality.**

ADAPTATION IN ACTION

Pecatonica River: Wisconsin Buffer Initiative Pilot Project

An experiment is taking place in southwest Wisconsin that could improve water quality in streams more efficiently and effectively. One of the challenges facing landowners and managers in Wisconsin and nationwide is keeping sediment and nutrients on the land and out of streams. Is there a way to target efforts to improve water quality so they have the greatest impact at the lowest possible cost? Farmers, University of Wisconsin scientists, public agencies and The Nature Conservancy through the Great Rivers Partnership are working together to answer this question. Known as the Wisconsin Buffer Initiative (WBI), the group hopes to improve water quality by using science to target conservation efforts on those fields and pastures with the greatest potential for contributing nutrients and sediment to streams. WBI is testing this approach in the Pecatonica River watershed. If successful, the partners will look for opportunities to implement it more broadly across the state.

Using research by University of Wisconsin graduate students and Dane County Land and Water Resources Department conservation staff, the partners have identified a handful of farms in one of the watersheds that contribute comparatively large amounts of phosphorus and sediment to the stream. Dane County conservation staff members are working with these farm owners to identify alternative management practices, including different types of tillage, crop rotations and manure handling, that will reduce the amount of sediment and nutrients entering the stream.

The goal is to identify conservation practices that are compatible with a farm's current cropping and livestock system and, where possible, increase or not significantly reduce profitability. Dane County has secured funding to help farmers implement needed changes that aren't financially feasible for them otherwise.

It will take several years for conservation practices to be fully implemented and begin to show results. Ultimately, however, the partners hope to demonstrate that targeting conservation practices where most needed will result in significant water quality improvements and provide the most efficient and effective use of limited resources.

If they are successful, the partners believe their research will create tools that streamline implementation of targeted conservation efforts in other watersheds. Their data will also be valuable to the agricultural community and other decision-makers in reshaping public policy related to water quality management not only in Wisconsin but across the nation.

Photo: Wisconsin Department of Natural Resources

Aerial view of Pecatonica River watershed.

Condensed from:
http://www.nature.org/wherewework/northamerica/states/wisconsin/files/pecatonica_river_fact_sheet.pdf

Conclusion

Agriculture is a major force in Wisconsin's economy and culture as well as a source of food security for the people of our state. Farmers need more information on how climate change will affect agriculture in order to safeguard crops and soil resources, make wise market decisions and engage in the best on-the-ground farming practices. Policy-makers will also need access to the best available information in order to craft the most effective policy responses to climate change.

We acknowledge that this is a preliminary assessment of climate change impacts on Wisconsin agriculture. This is the first effort at a statewide analysis; more detailed assessments will follow in the years ahead as climate modeling continues to improve and research on impacts expands in scope.

Source material for this chapter was drawn from the Agriculture and Soil Resources Working Group reports, available online at www.wicci.wisc.edu.

Photo: Avery Dorland

Changes Affecting Coastal Processes

Impacts and Vulnerabilities

Adaptation Strategies

Photo: Dave Miess

CHAPTER SIX

COASTAL RESOURCES

Wisconsin is one of 30 coastal states in the country and one of only eight states with a Great Lakes coastline. The southern shore of Lake Superior runs more than 150 miles along northern Wisconsin; an additional 175 miles of coast is created by Lake Superior's Apostle Islands. Along the state's eastern side, Lake Michigan – including Green Bay – provides more than 400 miles of coastline. Wisconsin boasts a wealth of coastal resources, including 38 cities and villages with frontage on the Great Lakes (figure 1).

Wisconsin's coastline includes natural resources such as bluffs, estuaries, wetlands, dunes and beaches as well as economic activities like shipping and tourism. Four of the state's largest cities, Milwaukee, Green Bay, Kenosha and Racine, are located on the coast, which exerts a powerful influence on the infrastructure, economy and culture of these urban centers.

Wisconsin's Great Lakes coastal regions will face the same changes in climate faced by land areas plus a few that are more prevalent over large lakes than on land. These include projected increases in air temperature; precipitation during fall, winter and spring; heavy precipitation events and evaporation resulting from warmer temperatures and reduced ice cover. In addition, wind strengths have increased over the lakes and are expected to increase more in the future. These climatic changes are expected, in different measures, to influence lake levels, coastal erosion, spring flooding and shoreline stability. Along with long-term changes in lake levels, we expect the natural variability that occurs over the course of decades to continue. All of these climate changes affect both the natural and built environments. Certain habitats and structures are more vulnerable than others.

Figure 1. Wisconsin's Coastal Counties.

Source: David Hart, University of Wisconsin Sea Grant Institute.

In this chapter, we discuss the effects of climate change on the natural and built environments of Wisconsin's coastlines, examine potential impacts and vulnerabilities, and recommend strategies for adaptation. Our information is in the early stages of development. Many uncertainties remain as climate projections improve and our understanding of the coastal zone advances.

Changes Affecting Coastal Processes

As discussed in previous chapters, climate change will affect natural and built habitats across the state, and the impacts of those changes will differ from region to region. The coastal regions of Wisconsin present unique vulnerabilities, and we focus here on three climate change effects that will impact the natural and built environments of the coast if temperatures continue to rise, precipitation increases, and intense rainfall events become more frequent:

Reduced ice cover: Historical analyses reveal that water temperatures in the Great Lakes have been increasing over the last 50 years and ice cover has decreased. In a study of Bayfield harbor in northern Wisconsin, records show that ice covers the lake 45 fewer days annually than it did 150 years ago. We expect these changes to continue.

Changing lake levels: Water levels are expected to decline slightly, on average, but also to continue to exhibit large variation over decades, as they have in the past 100 years or so (figure 2). The scientific consensus is that average water levels of Lake Michigan and Lake Superior will fall 0.8 to 1.4 feet by the end of the century, with Lake Superior falling less than Lake Michigan. The combination of warmer temperatures and reduced ice cover will contribute to greater evaporation, which will eventually exceed the increases in precipitation that have been occurring. Water levels will vary widely around their averages; hence, adapting to the variability in water levels and the long-term effects of climate change will require that we continue to address both high- and low-water decades. The general expectation is that by the end of this century, the

The combination of warmer temperatures and reduced ice cover will contribute to greater evaporation, which will eventually exceed the increases in precipitation that have been occurring.

High water and large waves combine to contribute to severe erosion at the base of bluffs. This bluff is on the Lake Superior shoreline.

Dredging may be required to deepen channels in marinas during periods of low water.

highest and lowest water levels will be slightly lower than they have been over the past 100 years.

Increasing wind strength: Scientists make the case for increasing wind strength over Lake Superior based on observations and physical dynamic simulations. Increased wind strength will lead to greater offshore wave development in the Great Lakes. With larger waves forming offshore, we can expect higher waves along the coast. These bigger waves will impact the shore-line, including bluffs, lakebeds and built structures.

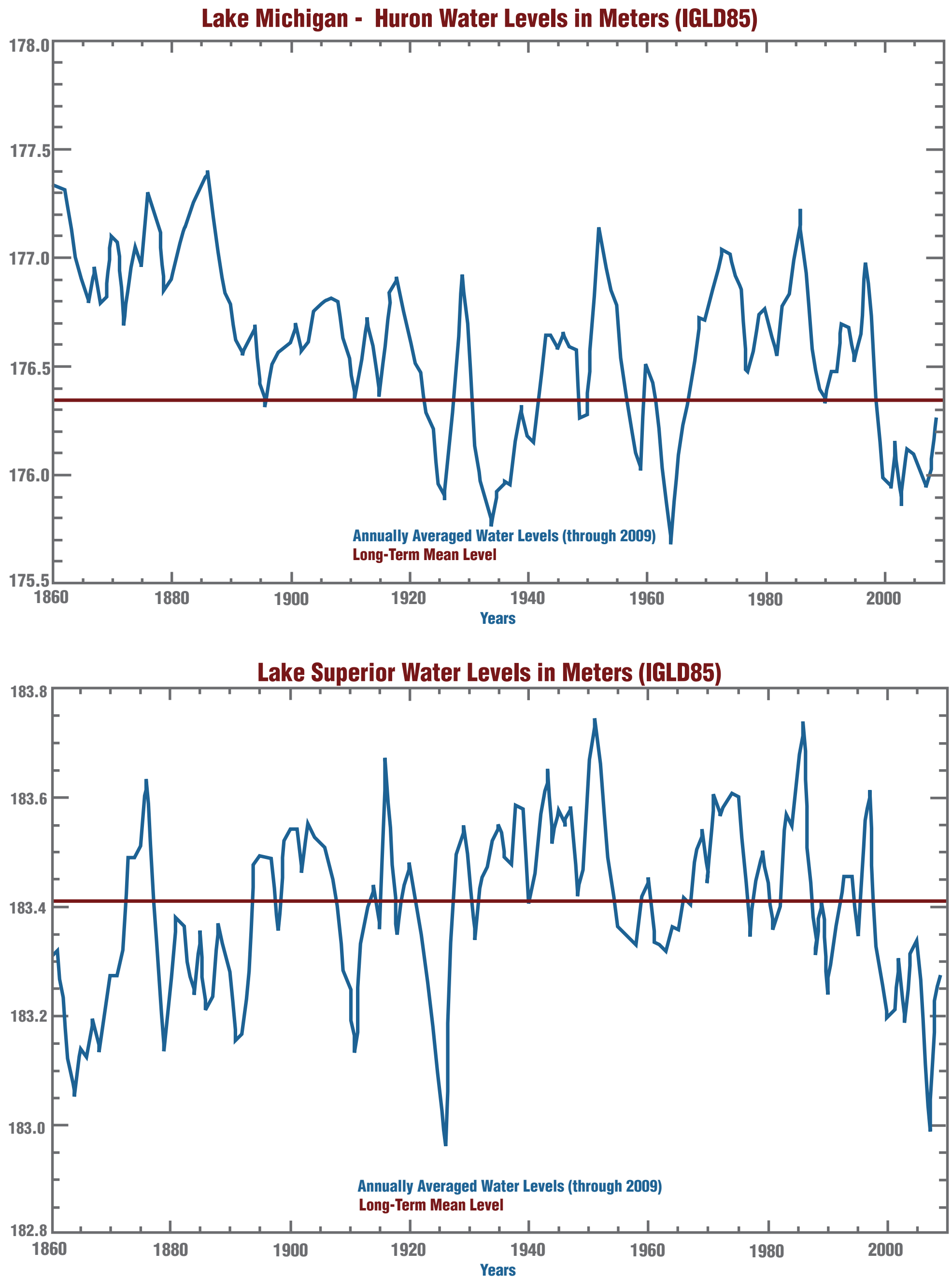


Figure 2. Fluctuation and average water levels of Lakes Michigan-Huron and Lake Superior since 1860.

Source: Great Lakes Environmental Research Laboratory, June 2010.

Impacts and Vulnerabilities

These effects of climate change on coastal resources will impact natural habitats such as beaches and wetlands as well as the facilities and infrastructure of the built environments along the coast. Below we discuss these impacts on a range of coastal habitats.

Natural Environment

Shore erosion and recession: Erosion is the process of wind, water or gravity transporting sediment, dirt and rocks from one area to another. As wind strength increases over the lakes, stronger waves could influence shoreline and lakebed erosion rates on Great Lakes coastlines. Additionally, with the lakes remaining ice-free for longer stretches of time, shorelines are exposed to waves for longer periods, causing more erosion. Large precipitation events are expected to be more common in fall, winter and spring, and the shorelines with less ice cover will be more vulnerable to these increased events. Bluffs could also become less stable if soils are saturated with moisture more of the time.

When lake levels drop and remain low for a long period of time, erosion or down-cutting of the lakebed will result (figure 3). This lakebed erosion will then allow more storm waves to reach farther inland when the water level eventually rises again and can lead to more severe shoreline damage.

A key factor in the stability of bluff soils is the amount of water in the soil. The friction between soil particles holds them in place, and when water fills those spaces, the soil becomes more fluid and less stable. This means that if climate change brings increased precipitation or heavy storms, an increase in the number of freeze-thaw cycles or higher lake levels, shoreline bluffs will become less stable and more susceptible to slumping – a process in which bluffsides collapse and slide downhill. Additionally, as Wisconsin sees the early onset of spring, early snow-melt – especially when accompanied by large rainfall events – can trigger bluff slumping as soils become saturated with meltwater.

On the other hand, drought or prolonged dry periods can also affect the stability of coastal bluffs. As bluff soils dry out, cracks a few inches deep can form, weakening the surface soils. If long-term drought occurs, deep fractures can form, allowing rapid access for surface water to penetrate deep into the bluff soils. If heavy rainfall events occur following a drought, they may cause rapid saturation of these dry, cracked bluff soils and cause major slope failure.

Shore recession – a consequence of erosion – is the apparent landward movement of a landscape feature such as a bluff or dune crest and refers to the change in distance from the feature's original position and its new, altered location after it has been eaten away by erosion. Recession is usually the most visible aspect of coastal erosion (figure 3); however, using it as an indicator of erosion can be misleading because a lag time occurs. Days, weeks, months or even years can pass after an erosion event before signs of recession become apparent on bluff shorelines. In fact, recession can occur during periods of little or no storm activity.

Flooding and runoff: Many factors – including wind, waves and water levels – contribute to coastal flooding. Climate change will influence these factors, either alleviating or increasing the threat of floods. And while the general consensus among scientists is that water levels in the Great Lakes will decline, they do naturally fluctuate and coastal flooding should continue in the high-water decades.

The combination of warmer, wetter winters and increases in intense storm events suggests also that Wisconsin will be dealing with increases in spring runoff in the future. More runoff will lead to longer periods of flooding in streams and associated wetlands, which will impact plant, animal and human communities in coastal areas.

Coastal wetland and near-shore impacts: Wetlands near the coasts of both Lake Michigan and Lake Superior provide rich habitat for plants and animals, and they greatly influence the larger processes of the Great Lakes ecosystem. Coastal wetlands comprise transitional zones, with vegetation changing from the submerged plants of the near-shore regions to the woody shrubs and swampy forests of the upland areas. They include marshes, bogs and swamps, and as transition zones between land and water, they are often rich in biological diversity and provide critical habitat for migratory and nesting birds, spawning fish and rare species. Their rooted aquatic plants anchor the sand and muck, keeping bottom sediments in place, providing habitat for fish and other aquatic species.

As Great Lakes water levels fall with climate change, stream channels will erode, delivering more sediment downstream to coastal wetlands and potentially burying natural aquatic communities. If water levels rise dramatically, coastal wetlands could be drowned out or severely eroded.

Additionally, coastal wetlands help prevent floods, protect shorelines and recharge groundwater supplies, but climate change will affect these habitats in many ways. Continued increases in temperature, changing lake levels and increased upland runoff and flooding will impact the food web, the make-up of plant communities and the overall quality of the wetland habitats.

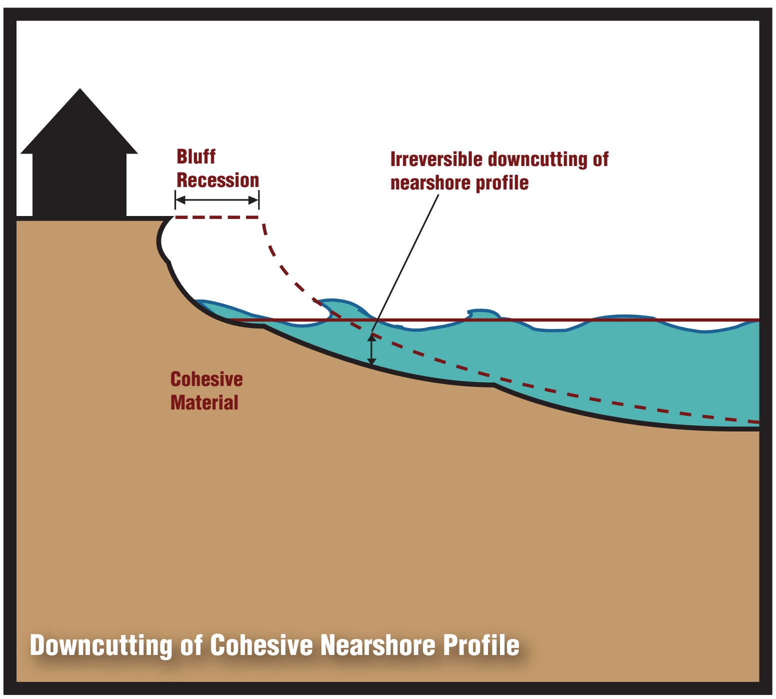


Figure 3. Lake bed downcutting is the gradual erosion of cohesive soil (clay or glacial till) in the nearshore area due to wave interaction. When most of the sand is stripped and the cohesive layer is exposed, cohesive material is lost to the water column. Unlike sand, cohesive material cannot be replenished by natural events such as bluff erosion. This erosion can result in recession of the shoreline.

Source: U.S. Army Corps of Engineers.

For example, plant diversity will decrease, and we could lose boreal wetland species altogether. Studies have shown that increasing temperatures allow seeds of weedy plant species to emerge and develop at higher rates than native species in boreal wetlands, giving weeds a competitive advantage if warming continues.

Changes in coastal wetlands increase opportunities for invasive species to take hold. Stormwater runoff can carry seeds of invasive species, distributing them throughout the landscape. Both flooding and drought put stress on aquatic plants, and invasive species can become established while native species are in a weakened state. For example, Lake Michigan wetlands are vulnerable to increasing introductions of the hybrid *Typha x glauca*, a cross between a native and invasive cattail, which can drive out native cattails and reduce biodiversity in sedge meadows on the Great Lakes coast. The hybrids are much hardier and more aggressive and can withstand a broader range of water levels than the native variety. In addition, when an area is frequently flooded, the phosphorus levels increase and the hybrid grows even bigger. Once an area is taken over by hybrid cattails, it may be difficult to restore to native sedges and cattails.

Changing lake levels will alter the ecology of the beach and near-shore habitat, with changes in fish spawning habitat resulting from wetland loss or siltation due to increasing erosion rates. As average lake levels drop, there will be a shoreward loss and a lakeward expansion of wetlands, resulting in a host of impacts, including those that affect fish living in streams and lakes by disconnecting some wetlands from the Great Lakes. If fish spawning and nursery habitat is impaired, we will see fewer young fish of certain species, and this will affect the overall health of fisheries, which are important to Wisconsin's culture and tourism.

Research on fishes also suggests that as warming occurs, warm water species will move from streams and lakes and invade the warming nearshore habitat, altering the nearshore fish community through predation on and competition with cool water species.

Beach health: As a coastal state, Wisconsin boasts an abundance of beaches along both Lake Michigan and Lake Superior. Our beaches are a major draw for tourism, and many Wisconsin residents spend their summers recreating on the shore. As temperatures rise, ice cover declines, followed by lower lake levels and altered beach ecosystems. These impacts will affect the integrity and aesthetic qualities of our state's beaches.

Across the state, elevated levels of bacteria are causing beach closings. Stormwater runoff and sewer overflow can be a major component of contamination, and as heavy rainfall events increase, scientists expect beach contamination to be more frequent and widespread, with runoff depositing sediments and pathogens on the beach. Increased water temperatures and longer ice-free periods will also create an environment that supports pathogens. At the same time, we can expect that Great Lakes beaches will become more popular as refuges from summer heat waves, leading to greater risk of illness among beachgoers.

Built Environment

Although beaches and wetlands compose much of Wisconsin's shoreline, coastal resources include a built environment as well. Ports, harbors and marinas dot the coastline, supporting industry, fishing and tourism. Homes and cottages sit atop bluffs and sandy beaches, and four of the state's largest cities – Milwaukee, Green Bay, Kenosha and Racine – are located on the coast. Our coastal landscapes include built features such as shoreline protection structures, drinking water intakes and water treatment plants. Climate change poses challenges for every component of the built coastal environment.

Ports, harbors and marinas: Wisconsin's ports, harbors and marinas are also vulnerable to the impacts of climate change. These structures include large-scale commercial operations and smaller recreational facilities with fixed or floating docks. The lifespan of maritime infrastructure is typically 40 to 50 years for marinas and slightly longer for ports and harbors. This longer planning horizon means that developers of these installations will need to account for climate

ORDINARY HIGH-WATER MARK

The ordinary high-water mark is the elevation on land at which the most permanent and prevalent water marks occur. Erosion, the destruction of terrestrial vegetation and other characteristics create the distinct signs of the ordinary high-water mark, which legally establishes the boundary between the publicly owned lakebed and privately owned land. This mark is the point from which Wisconsin's shoreland zoning setback is measured, so if lake levels are low for a long enough period of time that plant types shift from aquatic to land species, debate ensues regarding re-delineation of wetlands in this legal and policy context. If climate change lowers lake levels and the ordinary high-water mark moves lakeward, development and construction could follow, running the risk of future flooding if the lakes eventually return to higher levels. Given the large variation in Great Lakes water levels over decades, high-water mark definition and structural development should not closely track water levels; rather, they should be based on the water levels observed during high-water periods.

Photo: Dave Mickelson

Aerial photo (2007) of part of the Door County shoreline showing structures below the ordinary high-water mark of Lake Michigan. Dashed line in photo represents ordinary high-water mark.

events that will occur in the future because water level changes outside of normal lake fluctuations can greatly impact these facilities and their infrastructure.

Lower Water Levels

The scientific consensus suggests that, on average, Great Lakes water levels will be slightly lower by the end of the century; however, the large variations that occur over decades will continue to occur, resulting in high-water decades and low-water decades.

The slow trend toward lower water levels will result in a variety of impacts on coastal resources. For instance, lower water levels create situations in ports and harbors where ships cannot be fully loaded or may need to carry less cargo per trip. Vessels may hit the channel or slip bottoms, requiring additional dredging. For marinas, boat bottoms may be damaged by shallow depths, and the vertical distance between the docks and water level may increase, posing a hazard to people.

Higher Water Levels

High-water decades also have implications for ports, harbors and marinas. When Great Lakes water levels increase during high-water decades, the higher water weakens and destabilizes infrastructure and creates the potential for flooding of critical land areas and operational structures. The interaction of higher water levels and intense storm events increases the risk of damage from large waves and surges. Navigation and mooring, as well as access to docks and other structures, will also be affected.

Dredging and re-suspension of contaminated sediments: Some of Wisconsin's harbors and marinas contain contaminated sediments. If water levels are lower on average and navigation channels require additional dredging, buried toxic sediments may be exposed and re-suspended in the water. Lower water levels, more intense rainfall events or a combination of these conditions could also increase stream scouring and erosion, leading to more sedimentation downstream in Great Lakes bays and rivers, potentially exposing these areas to re-suspended pollutants.

Water Intakes

As water temperatures increase and ice cover decreases, blue-green algae may get a jump start on producing their toxic blooms. Changes in lake currents may alter areas where pollutants concentrate, and increased storm intensity will impact stormwater volumes, increasing polluted runoff and even sewer

overflows. Such changes could result in additional pollutants entering water intakes.

Changing lake levels will also affect water intakes. Lower lake levels may reduce the concentration of oxygen in the lakes; lower oxygen levels would further contribute to blue-green algal blooms. If water levels became low enough, drinking water intakes could end up at depths that are subject to greater algal abundance, mussel growth or suspended sediments. The lake ice that remains may interfere with water intakes, and the dredging of harbors and marinas may affect water quality.

Shoreline infrastructure: Infrastructure, homes and businesses, water and sewer operations, and recreational facilities located along the shoreline are vulnerable to changing lake levels, increased storms impacts and coastal erosion.

Millions of people living around the Great Lakes depend on vulnerable lakeside facilities. In areas with high bluffs, roads along a coastline can become vulnerable as the bluff recedes due to erosion and becomes unstable, posing challenges to engineers and residents.

COUNTY LS IN NORTHERN SHEBOYGAN COUNTY

In 2003, sections of Sheboygan County Highway LS were within 10 feet of the edge of a 70-foot-high bluff overlooking Lake Michigan. During a site visit by federal, state and local officials and property owners, the group conversation suddenly stopped as everyone's eyes fixed on a school bus as it drove by the area of concern. The next day Wisconsin Sea Grant coastal engineers sent a certified letter warning the county of the potential consequences of the bluff collapsing. While the road was never closed, school buses were rerouted. The county got the U.S. Army Corps of Engineers to design and partially fund an emergency shoreline protection project to protect this segment of the road. Unfortunately, an additional mile of road to the north remains within an unstable erosion hazard area along the bluff.

Photo: Elizabeth Katt-Reinders

Source material for this chapter was drawn from the Coastal Communities, Green Bay and Water Resources Working Group reports, available online at www.wicci.wisc.edu.

Adaptation Strategies

Because many factors can contribute to climate impacts on coastal resources, there is a wide range of possible strategies for adaptation. In keeping with the organizational framework presented in Chapter 2: *Understanding Adaptation*, we present here several adaptation strategies that pertain to the natural and built environments of Wisconsin's coastal areas. (Please see the working group reports at www.wicci.wisc.edu for a more detailed discussion of adaptation strategies.)

ADAPTATION

TAKING ACTION

Coastal Bluff Recession

Move buildings and roads back from the bluff edge and/or stabilize bluffs. Counties and municipalities should re-examine their setback ordinances to be sure that they account for likely increases in the bluff recession rate.

Coastal Site Design For Stormwater Runoff

An increasing frequency of large magnitude rainfall events requires control of surface water runoff along the shoreline and on bluffs. Possible actions:

- Develop erosion control and stormwater management plans.
- Do not construct stormwater infiltration systems (for example, rain gardens) unless they are specifically adapted to avoid destabilizing the bluff.
- Locate septic system drain fields away from bluffs and gullies.
- Preserve existing grass and trees and re-vegetate disturbed areas as soon as possible.

Ports, Harbors and Marinas

Anticipate and plan for greater dredging and the potential need for additional bottom scour protection at the base of harbor dock walls during periods of lower water levels. Anticipate potential dock top elevation modifications or modified loading/unloading procedures for periods of higher water levels.

Ports and harbors can increase the working dock heights, modify loading/unloading operations or relocate important facility features to higher land to protect against flooding. Marinas can adapt to changing water level extremes by converting fixed dockage to floating dockage.

Ports and harbors can adapt to increased wave action, seiches and storm surges by rehabilitating, modifying or replacing weaker portions of their infrastructure to withstand greater wave forces. Marinas can adapt by using stronger dock designs.

Adaptation strategies for hardening existing shoreline structures against potential climate change must be considered and implemented if needed, and new structures must be designed with potential climate change impacts in mind.

Proactively address contaminated sediment sites not within Great Lakes Areas of Concern and develop improved funding options for remediation.

Implement Comprehensive Community Planning

Growth and development management (zoning, redevelopment restrictions, conservation easements and compact community design).

Property protection (acquisition, relocation, setbacks, building codes, retrofitting, infrastructure protection and shore protection structures).

Shoreline management (regulation and removal of shore protection structures, rolling easements, living shore-

Conclusion

Climate change poses a variety of challenges to Wisconsin's coastal resources, both natural and built. Some of our state's most fragile ecosystems lie in coastal zones along Lake Superior and Lake Michigan. Four of our largest cities reside on the shore of Lake Michigan, and billions of dollars of economic activity are generated in Great Lakes coastal zones. Adaptation to the likely and potential impacts of climate change poses significant challenges for natural resource managers, urban planners, infrastructure designers and others whose decisions affect – and are affected by – these vital components of Wisconsin's landscape, economy and culture.

STRATEGIES

lines, beach nourishment, dune management and sediment management).

Water Intakes

Implement water conservation measures to offset any increased need for exploiting Great Lakes water to offset decreasing groundwater supplies.

Beach Health

Use best stormwater management practices to reduce runoff and prevent polluted runoff from urban and agricultural areas, along with beach grooming to reduce pathogens and consequent beach closures (for example, reducing impervious surfaces and increasing buffers near beaches will help control stormwater runoff).

Monitor water quality at beaches and communicate results that may lead to beach closures but likely will prevent illness.

Coastal Ecosystems

Implement coastal and aquatic ecosystem management (ecological buffer zones; open space preservation and conservation; ecosystem protection and maintenance; ecosystem restoration, creation, and enhancement; and aquatic invasive species management).

BUILDING CAPACITY

Shoreline Structures

Develop adaptation strategies for conditions where lake levels may drop below historic levels, making shore protection structures in coastal reaches unnecessary for the purpose of protecting coastal slopes from wave action.

COMMUNICATING

Water Intakes

Infrastructure planning should consider the relocation of water intakes and increased water treatment needs from changing lake levels.

Anticipate increases in runoff volume to avoid sanitary sewer overflows, increased erosion and polluted runoff that can contaminate water supplies.

Tourism

Locate hotels and recreational facilities to avoid future access and erosion problems.

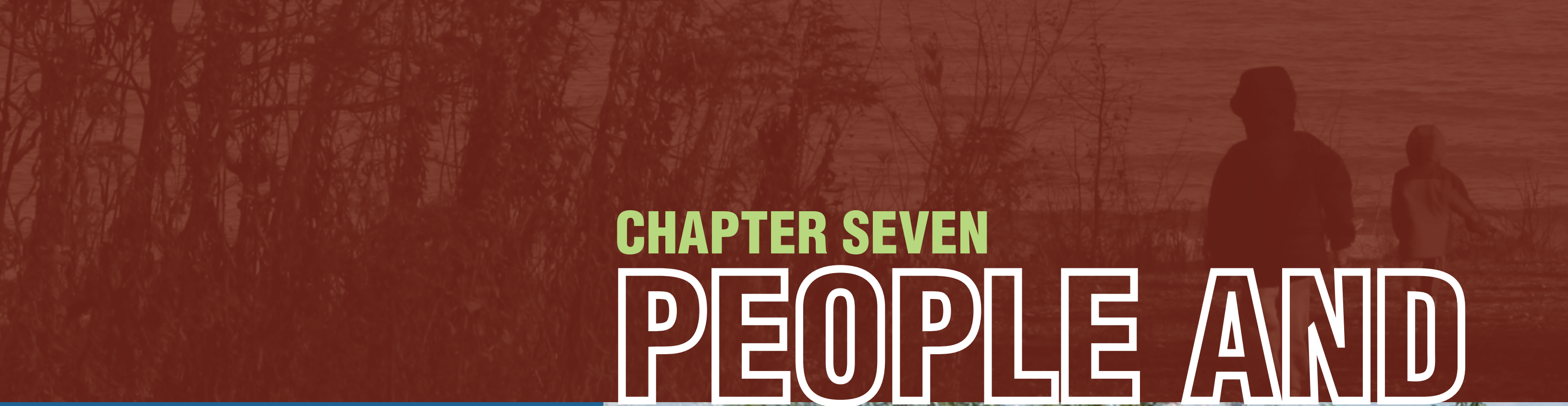
Lakeshore Communities

Target community lakeshore planning to provide for multiple-landowner boat access under variable water levels and low-impact marina siting.

FILLING GAPS

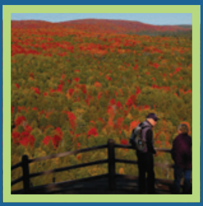
Contaminated Sediments

Use bathymetric data to identify port, harbor and marina facilities that are at risk from re-suspended sediments. Work with the owners to develop strategies to adapt to changing lake levels and identify alternatives to dredging.



CHAPTER SEVEN

PEOPLE AND

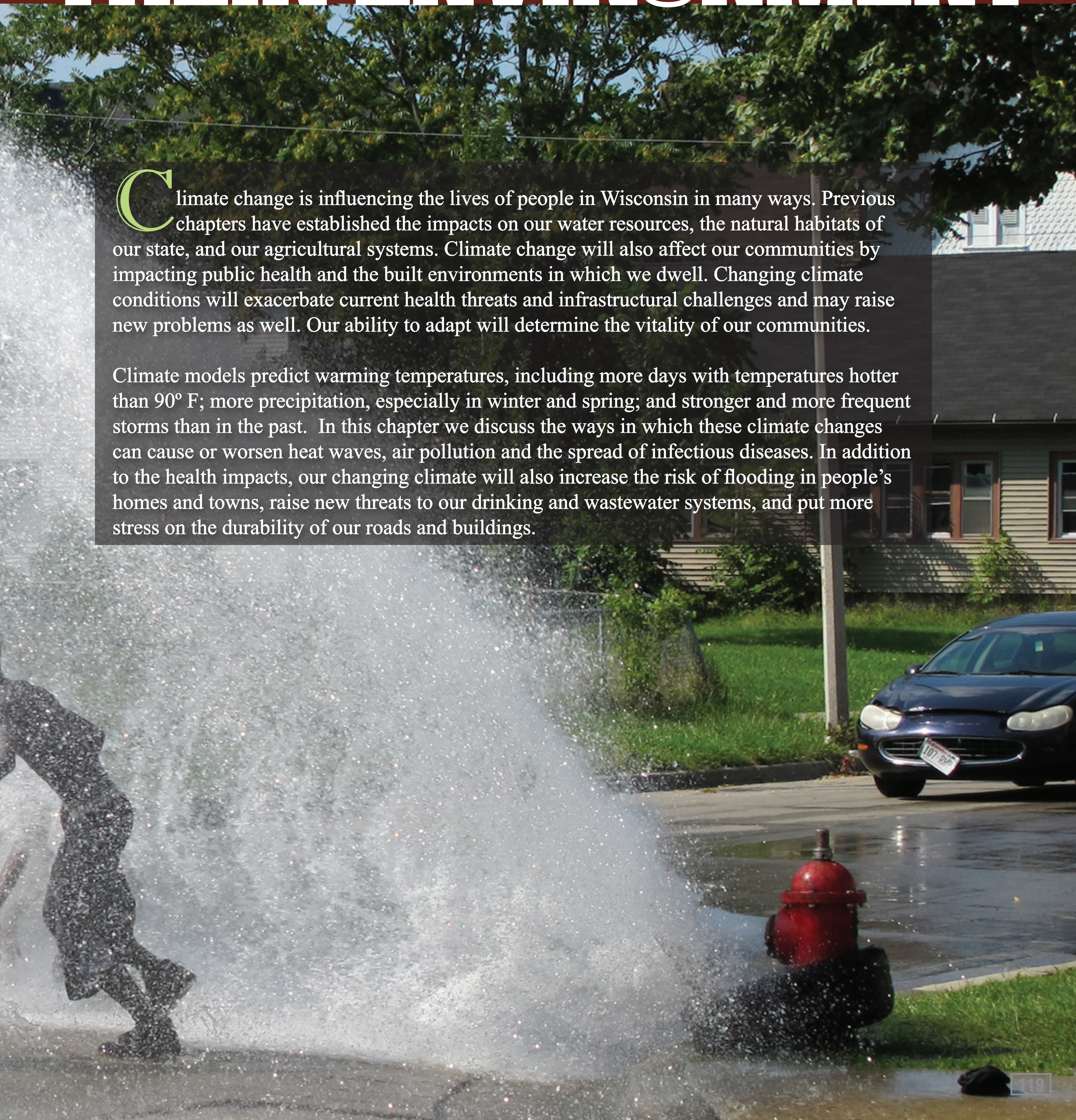


Impacts and Vulnerabilities

Adaptation Strategies

Photo: Courtesy of Finn Ryan and Climate Wisconsin

THEIR ENVIRONMENT



Climate change is influencing the lives of people in Wisconsin in many ways. Previous chapters have established the impacts on our water resources, the natural habitats of our state, and our agricultural systems. Climate change will also affect our communities by impacting public health and the built environments in which we dwell. Changing climate conditions will exacerbate current health threats and infrastructural challenges and may raise new problems as well. Our ability to adapt will determine the vitality of our communities.

Climate models predict warming temperatures, including more days with temperatures hotter than 90º F; more precipitation, especially in winter and spring; and stronger and more frequent storms than in the past. In this chapter we discuss the ways in which these climate changes can cause or worsen heat waves, air pollution and the spread of infectious diseases. In addition to the health impacts, our changing climate will also increase the risk of flooding in people's homes and towns, raise new threats to our drinking and wastewater systems, and put more stress on the durability of our roads and buildings.

Impacts and Vulnerabilities

Public Health

While climate change in Wisconsin will bring some benefits to human health, such as fewer deaths from exposure to very cold temperatures,scientists agree that, overall, we will see more negative than positive climate impacts on health. Climate change poses regional and local public health risks in Wisconsin that will vary depending on the season, geographical location and physical characteristics of a landscape. The severity of the impacts depends on the age, health and other demographic characteristics of the population; the level of resources and preparedness of local public health agencies and communities; and the physical location of the affected areas. Climate can influence human health directly, such as by causing death or illness from exposure to extreme heat for an extended period of time, or indirectly, as when climate changes foster the spread of diseases or increase exposure to pollution.

> We will see more negative than positive climate impacts on health.

In this section, we focus on the direct impacts of heat waves and the indirect impacts of air pollution and infectious diseases, both water- and vector-borne. Our understanding of the full extent of climate change impacts on human health on a state and local scale is in its infancy. This is our first assessment of climate change impacts on public health in Wisconsin, and there is much work left to do. While this assessment includes a broad range

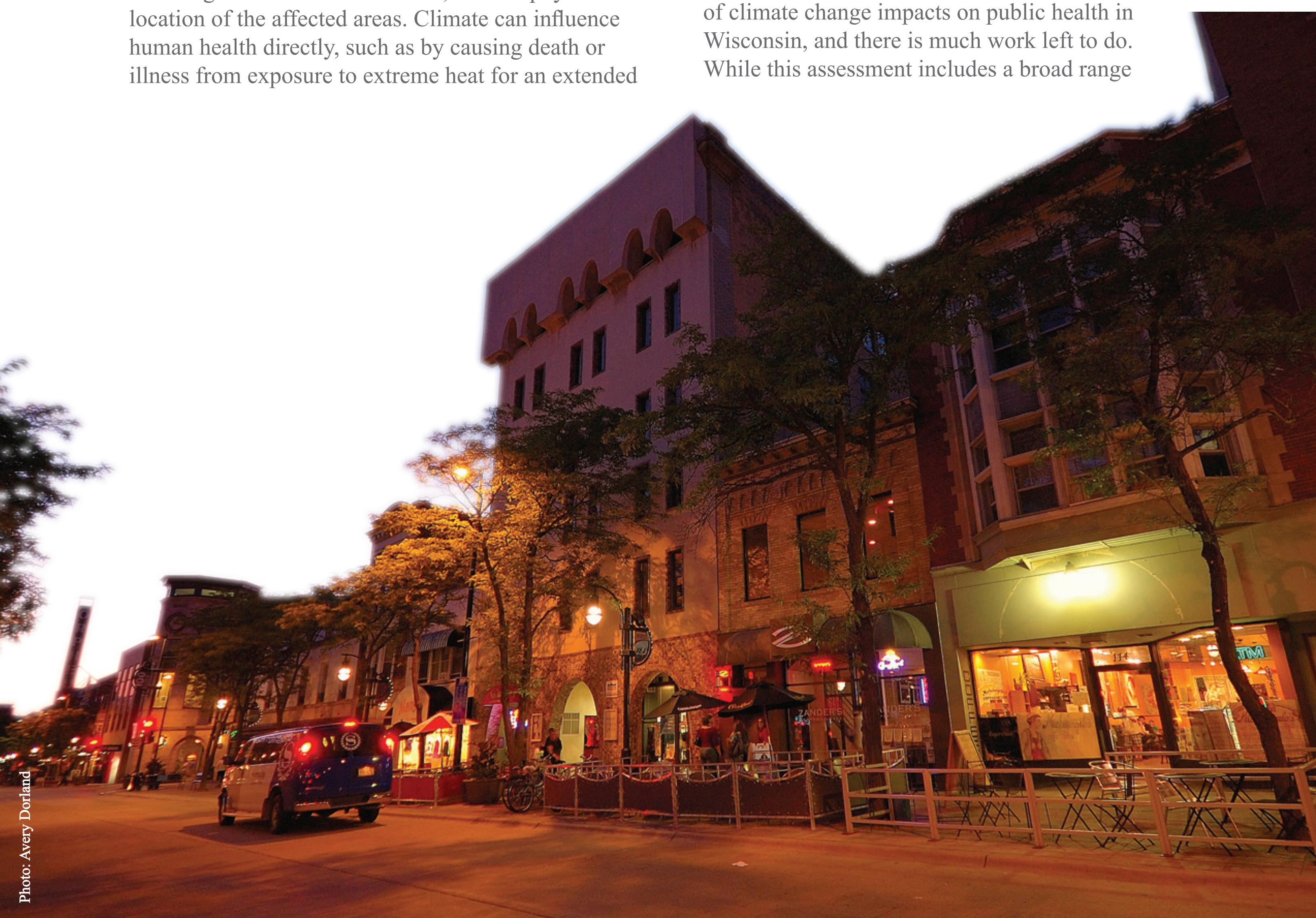
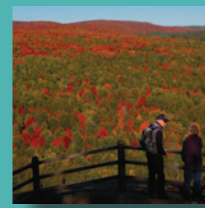


Photo: Avery Dorland



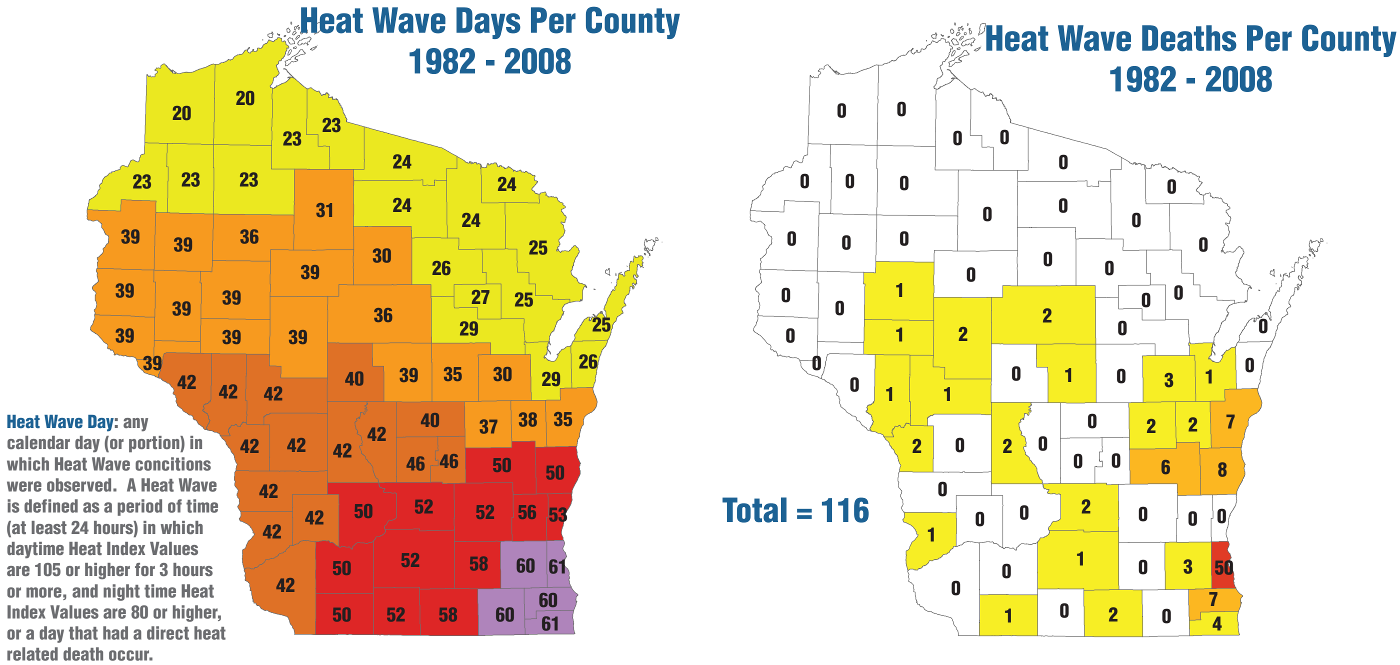


Figure 1. Number of heat advisory days and number of heat-related deaths in Wisconsin by county in 1982-2008. Milwaukee County has a disproportionate number of heat-related deaths due to dense population centers.

Source: National Weather Service.

of health impacts, ongoing work at the university and in local, state and federal agencies to further assess and plan for the public health impacts of climate change will contribute to future WICCI reports.

Heat Waves

According to the U.S. Environmental Protection Agency, heat waves have become more frequent across the country over the last 40 years, and they also are becoming longer and more intense. Heat waves, prolonged periods with stagnant air masses and temperatures over 90º F, have direct impacts on human health, and scientists expect to see more by the end of the century. When hot conditions continue for several consecutive days with little to no relief, a substantial number of deaths and illnesses can occur, especially among the youngest and oldest in the population.

A recent analysis by University of Wisconsin scientists revealed an increase in hospital admissions in Milwaukee during heat waves. Some of these admissions, especially involving children and the elderly, could be attributed to high temperatures.

Cities are particularly vulnerable to heat waves because of the "urban heat island effect," in which urban areas become warmer than the surrounding rural areas because of the dry, impervious characteristics of their buildings, roads and other paved surfaces. Brick buildings, asphalt streets and tar roofs store and then radiate heat like a slow-burning furnace. Heat builds up during the day, and cities take longer to cool down at night than surrounding rural areas.

Southern Wisconsin experiences more days of heat waves than other parts of the state, and Milwaukee County has reported the highest numbers of heat-related deaths. Figure 1 illustrates the number of heat advisory days and heat-related deaths by county.

Photo: David S. Liebl

Smoke from residential wood heating can be a significant source of fine particle air pollution.

Air Pollution

Research has established that exposure to air pollution increases the risk of respiratory diseases such as allergies, asthma and chronic lung diseases as well as the risk of heart disease. Air pollution could worsen with climate change, posing greater threats to public health. Prevalent air pollutants in Wisconsin include smog, particulate matter and airborne allergens.

Smog: Scientists expect that as temperatures continue to rise, air pollutants such as ozone will become a greater concern for public health. Ground-level ozone, or smog, is not emitted from a particular source; rather, it is a secondary pollutant that forms when hot air, sunlight and emissions from a variety of sources react in the atmosphere. This reaction depends heavily on high temperatures and ultraviolet energy from the sun, so the problem is at its worst in summer. Projections of increasing temperatures lead scientists to predict an increase in the formation of smog.

Smog damages lung tissue, and public health scientists have described the irritation as "sunburn on the lungs." Smog worsens conditions such as asthma and chronic lung diseases, and it is particularly risky for children because they often spend considerable amounts of time in activities outdoors, where they are more likely to inhale air pollutants and to breathe them deeper into their lungs.

Climate projections for the coastal regions along the southern shores of Lake Michigan suggest we will see an increase in smog in those areas. These projections include warmer temperatures with related changes in air circulation, humidity, cloud cover and precipitation. According to a study of ozone pollution in Chicago – located at the southern tip of Lake Michigan only 55 miles from Kenosha – these meteorological changes alone could result in an increase in the number of days when these coastal regions exceed the current National Ambient Air Quality Standards for ground-level ozone, growing from an average of 2.2 days per summer to up to an average of 16.8 days by the end of this century.

Although Wisconsin has made significant progress in reducing ozone levels, we will face greater challenges in meeting the federal regulations as climate change increases the conditions that lead to ozone formation.

Particle pollution: Particle pollution, also called particulate matter, is another form of air pollution that aggravates asthma and increases respiratory and heart disease. Particle pollution consists of a complex mixture of miniscule solid particles and liquid droplets that are suspended in the air and made up of a variety of components, including nitrogen oxides and sulfur dioxides. Some components of particle pollution are emitted directly from power plants, industrial sources, vehicles, agricultural sources, forest fires or wood stoves, while others form from chemical reactions in the atmosphere.

Particles such as dust, soot, smoke and dirt can be large or dark enough to see. Such pollution creates the white or brown haze that lingers over many areas of the United States, reducing visibility. Other smaller particles, called fine particulates, are so tiny they can be seen only through a microscope. These fine particulates can cause severe health effects because they are small enough to be inhaled into the deepest parts of the lungs and become trapped, potentially leading to lung disease, asthma, emphysema or heart disease.

Unlike smog, which is worse in hot months because of its dependence on sunlight and high temperatures, particle pollution can reach unsafe concentrations at any time of year. Milwaukee, Racine and Waukesha counties currently do not meet National Ambient Air Quality Standards for fine particle pollution. If Wisconsin faces climate conditions more favorable to the formation of particle pollution, such as warmer winters coupled with increased water vapor in the air, the combination may result in an increase in concentrations of particulate matter, posing greater threats to public health.

Airborne allergens: Airborne allergens can interact with other forms of air pollution, increasing the risk of respiratory diseases and other public health challenges. One of these pollutants is pollen. Higher levels of carbon dioxide – one of the greenhouse gases that have been increasing and continue to increase in the atmosphere – promote growth and reproduction by many plants, including those that produce allergens. For example, ragweed plants experimentally exposed to high levels of carbon dioxide can increase their pollen production several-fold, which some scientists suspect may be part of the reason for rising ragweed pollen levels in recent decades. This common allergen can aggravate asthma and other respiratory diseases.

Waterborne Disease

Studies have shown that heavy rainfalls and watershed land use patterns are associated with waterborne disease outbreaks. Land use patterns and the presence of human and animal waste make some watersheds more vulnerable to water contamination, especially after a heavy rain. Contamination of water results from a variety of causes including runoff from storms, contamination of wells or distribution pipes in areas of aging infrastructure, and sanitary sewer overflows that release sewage into waterways.

Combined sanitary sewer overflows: Contamination from sewage overflow is a major source of human pathogens and adversely impacts recreational beaches and drinking water sources. Older cities in the Great Lakes region, including Milwaukee, have combined sewer systems that handle both sewage and stormwater in large underground pipes. When rainwater inundates these systems following a heavy downpour, the pipes can overflow into surface waters like lakes and streams, posing a health risk from contamination.

Gastrointestinal illness and respiratory effects are all public health concerns that result from this type of contamination. While sewage is detectable in surface waters even under normal conditions, precipitation is a major driver of sewage delivery into surface water.

When rainwater inundates these systems following a heavy downpour, the pipes can overflow into surface waters like lakes and streams, posing a health risk from contamination.

Photo: Gabor Bibor

Besides the direct effect of flood-related deaths, flooding can spread harmful bacteria and viruses.

Therefore, if instances of heavy rainfall increase in frequency and magnitude, as climate models project, we will see an increase in these public health risks resulting from sewer overflows. A notable example of waterborne disease outbreak resulting from heavy rainfall is the 1993 *Cryptosporidium* outbreak in Milwaukee, when an estimated 400,000 people were exposed and 54 people died. The outbreak occurred following heavy rainfalls and coincided with combined sewage overflows and near-record flows in the Milwaukee River that delivered runoff from upstream agricultural areas.

Flooding: Flooding poses additional human health risks. Besides the obvious direct effect of flood-related deaths, flooding can spread harmful bacteria and viruses. During 2007-08, Wisconsin experienced very large precipitation events that took a toll on public health. When a mid-August torrential rainfall fell on the heels of a drought, the rainfall landed on hardened ground, triggering large-scale flooding in southern Wisconsin. That winter brought record snowfalls for the region, with 101 inches falling in Madison, and as the snow melted into already saturated ground, river levels rose higher than they had been in decades, with floodwaters reaching the 100-500 year floodplains. The following June, severe weather swept through the entire Midwest, impacting already-flooded regions across the state and contaminating food and water supplies across southern Wisconsin. Some 41,000 households filed for emergency assistance, and more than 2,500 drinking water samples were tested. More than 30 percent of these samples proved to contain coliform or *E. coli* bacteria.

Vector-Borne Disease

Many diseases that begin their life cycle in animals, such as West Nile virus and Lyme disease, are sensitive to fluctuations in climate. The timing of peak years of West Nile outbreaks coinciding with unseasonable heat waves led scientists to investigate the effect of temperature on the ecology and transmission of the disease. They found that a West Nile outbreak in horses in the Midwest peaked during periods of high temperatures and dropped significantly following decreasing temperatures. These findings suggest a temperature effect, and scientists continue to study the possible link.

> Unless we modify planning, design and management of infrastructure, the risk of economic and environmental damage will increase.

Even slight changes in temperature and moisture can go a long way toward changing the risk of transmission and determining the geographic range of a disease host. Such changes could make the world more hospitable for the tiny animals that transmit diseases. For cold-blooded insects and invertebrates such as mosquitoes and ticks, all it takes is a small shift in temperature to alter their transmission dynamics. Moisture is another factor that determines the survival of ticks, and increased dryness lowers tick survival rates. As long as there is adequate moisture, warmer conditions promote tick abundance.

The reported incidence in Wisconsin of Lyme disease, which is transmitted by ticks, has consistently been among the 10 highest among states in the U.S. and has doubled in the past decade. However, preliminary results from Lyme disease research by the Human Health Working Group and Canadian scientists suggest that climate change may be expanding the range of ticks northward, sending them out of Wisconsin and into Minnesota and Canada by the end of this century.

Moreover, other factors complicate Lyme disease predictions. Scientists question whether the increase in Lyme disease may be more a function of land use than of climate. This is one area at the interface of ecology and human health that is extremely important and illustrates the potential intersection of conservation and land use policy with public health policy. For example, the fragmentation of wooded areas sets up conditions for the ticks that spread Lyme disease. Large predators do not do well in isolated fragments of woodlands, and this allows populations of rodents and other small animals to grow. Rodents often carry Lyme disease, and they are also an ideal host for ticks. The infected rodents infect the ticks, and the ticks move on and spread the disease to people and their pets.

Built Environment

Climate change will compound the challenges that people and their environments already face. Buildings, roads, and water and sewer systems will face different weather conditions than in the past, and current designs do not equip infrastructure to withstand the challenges that future climate changes may bring.

Unique challenges arise when concentrated populations of people live amid aging or inadequate infra-

Photo: Elizabeth Katt-Reinders

Heavy rainfall amounts can exceed the capacity of stormwater systems in urban areas, leading to localized flooding.

structure. Society's infrastructure is built to manage the risks and impacts associated with precipitation and weather patterns, but it has been traditionally designed and evaluated using historical data. For example, sewer systems are designed to accommodate the additional flow that follows a heavy storm. Bridges and culverts are built to allow safe passage over streams and rivers under all but the most extreme flood conditions. However, climate models project an increase in heavy storms that needs to be taken into account in current designs. Unless we modify planning, design and management of infrastructure, the risk of economic and environmental damage will increase.

Runoff and Flooding

In Wisconsin's urban watersheds, stormwater runoff and sewer overflows are primary factors in water quality issues. Increases in the magnitude and frequency of large daily or shorter duration rainfalls are the most relevant climate change impacts, and they will require greater investments in stormwater infrastructure for both new and existing development.

In rural areas, nutrient and sediment runoff from agricultural lands is a critical water quality concern. As is the case with urban watersheds, changes in the magnitude and frequency of rainfall events are critical, but more significant is the projected shift in precipitation to winter and spring. Agricultural lands are particularly vulnerable to large rainfall events that occur in the spring when soil is bare and there is no evapotranspiration. Nutrient and sediment runoff from agricultural watersheds is likely to increase as a result of projected increases in the magnitude and frequency of large rainfalls and in winter and spring precipitation.

Photo: FEMA 2008

Crawfish River

It appears that climate change in Wisconsin will produce modest annual increases in daily rainfall over the next century, resulting in greater storm flows in urban watersheds. Projections by the Climate Working Group indicate that in southeastern Wisconsin the number of storms with daily rainfall totals of two inches or more will likely increase in frequency from the current 12 storms per decade to 14 to 15 storms per decade. This change could affect the performance of stormwater management systems and of flood mitigation efforts. It could also expand flood hazard areas, encompassing more existing development. With an increase in the magnitudes of rainfall comes an increased risk of flood damages and a need for larger, more costly stormwater management and flood mitigation facilities and programs.

Heavy rainfall amounts can exceed the capacity of stormwater systems in urban areas, leading to localized flooding. A number of factors influence the volumes and rates of runoff to stormwater management systems and receiving streams. The factors most likely to be influenced by climate change include the amount of rainfall, timing of storm events, and frequency and intensity of precipitation, followed by changes in temperature and humidity that may affect evapotranspiration. Other factors that come into play include leaf canopy, the amount of impervious land surface, infiltration capacities of pervious surfaces, land surface slopes, natural and constructed runoff storage and infiltration facilities, evapotranspiration of water from the ground surface and soil, and the capacity of the soil to store moisture.

Locally, stormwater causes high-water conditions as a result of heavy rainfall over relatively small areas, especially when the duration of the initiating storm event lasts only minutes to hours. Furthermore, a large portion of an urban watershed is usually impervious; therefore, soil moisture conditions have little effect on the rate of surface runoff. For these reasons, the design of stormwater infrastructure is usually based on single storm events. For urban stormwater management, changes in the magnitude of rainfall at the daily or shorter time scale are the most relevant.

Stormwater management systems typically include infrastructure designed to handle small and mid-range storms as well as to safely handle runoff from large storms that have a statistical probability of 1 percent chance of occurring in a year. Flood mitigation planning and facilities are generally focused on flood events with annual probabilities of occurrence of 1 percent or less.

GROUNDWATER FLOODING IN BRODHEAD

During 2007-08, southern Wisconsin experienced above-normal precipitation and intense rainfall events. Rising regional groundwater levels resulting from increased recharge caused groundwater flooding of basements and yards. Low-lying developed areas situated over shallow groundwater (less than 10 feet) and with poor surface drainage reported continuously running sump pumps during this period. Several houses became uninhabitable due to persistent soil saturation and flood damage.

Long-lived infrastructure that is vulnerable to high-water conditions or that protects against the impacts of high-water conditions is of particular concern. This includes water supply systems, wastewater treatment systems, bridges and culverts as well as infrastructure that controls floods (such as dams and levees), manages stormwater, and controls soil and stream bank erosion.

The design of such infrastructure has been and continues to be based on historical precipitation and flood data. Unless appropriate adaptation strategies are adopted, we can expect increases in the frequency and severity of the following high-water impacts:

- Roadways and bridges washed out by high water or slope failure.
- Contamination of rural residential wells as a result of surface water and groundwater flooding.
- Flooding of urban streets and homes due to inadequate runoff drainage systems.
- Failure of impoundments, levees, and stormwater detention ponds.
- Failure of rain gardens and other biofiltration practices due to prolonged periods of saturated soils.
- Stormwater inflow and groundwater infiltration to sanitary sewers, resulting in untreated municipal wastewater overflowing into lakes and streams.
- Groundwater flooding of property and cropland.

Groundwater drains much more slowly than surface water. High groundwater results when recharge exceeds drainage over periods of months or years. As with streams, rivers and lakes, the expected increases in winter and spring precipitation (when recharge is unaffected by transpiration) are likely to have the greatest impact on the occurrence of high groundwater conditions. As for runoff, the critical factors determining the amount of recharge versus runoff are soil type, soil moisture, vegetation and frost. Homes and businesses built over former wetlands are vulnerable to flooding from rising groundwater caused by climate change.

> An increase in the number of intense rainfall events and high groundwater that cause inflow and infiltration will lead to increased frequency, size and duration of sanitary sewer overflows and residential floor drain backups.

Wastewater

Climate change poses potential risks to wastewater treatment facilities in Wisconsin. The changes that may have the greatest potential influence are an increase in the number of intense rainfall events and high groundwater that cause inflow and infiltration, leading to increased frequency, size and duration of sanitary sewer overflows and residential floor drain backups. In addition, these events could result in physical damage to treatment facilities, short-term loss of treatment capacity and increased need for inspection and maintenance. The potential also exists for increased risk of losing the biologic activity in wastewater treatment facilities, which could make it difficult to meet water quality standards and associated discharge limits.

Warmer and dryer summers can result in reduced wastewater system flows. This could lead to odors, more sewer pipe corrosion and an increased risk of sewer blockages due to stimulated plant growth and material deposit. Dry weather followed by intense precipitation events also poses operational issues for both wastewater collection and treatment systems. These issues manifest themselves in terms of highly variable wastewater strength and plant loadings, and, ultimately, as challenges in maintaining discharge-permit compliance.

Sewage overflows pose a serious health risk stemming from the introduction of pathogens into the environment. Combined and sanitary sewer overflows occur when the volume of heavy rainfall or groundwater infiltration exceeds the capacity of a sewer system. Projections of increased intensity and frequency of heavy rainfall events, particularly in spring when groundwater tables are often elevated, are likely to lead to increases in the number of sewage overflows.

Drinking Water

Lakes Michigan and Superior constitute the primary water supplies for Wisconsin's coastal communities. Climate change impacts may alter the treatability of lake water. At the intakes, lake level has an important effect on pumping requirements, on the formation of ice blockages in winter and on the potential

BARABOO RIVER AT I-90/94/39

The flood damage experienced in Wisconsin in 2008 exposed many weaknesses in current strategies to protect against high-water conditions. In many cases, these weaknesses are being addressed. For example, the Wisconsin Department of Transportation is conducting a review of the vulnerability of the entire interstate highway system as a result of flood-triggered closures of I-39, I-90, and I-94 at the Baraboo River in Columbia County. Engineers will weigh the costs of flood-proofing stream crossings and embankments against the economic costs of temporary closures of this important roadway.

for invasive species to impact both water quality and water utility infrastructure. Water temperature, biological and chemical contaminant types and loads, and amounts and sizes of suspended materials requiring physical removal all have an effect on lake water treatability. For example, the amount and sizes of suspended materials are typically driven by the occurrence and magnitude of storm events. The magnitude, frequency and duration of changes of in-flowing water characteristics could complicate treatment and possibly necessitate infrastructure improvements in treatment processes, especially if these changes occur sporadically.

Climate change may make drinking water distribution systems more vulnerable. If climate change leads to an increasing number of freeze-thaw cycles, it can, in turn, cause higher numbers of water main breaks and greater incidences of leaks that result in unaccounted-for water.

Climate changes may also drive shifts in water-use patterns outside the immediate coastal communities, which could expand the demand for lake water. These changes and challenges could then impact decisions related to expanding or replacing drinking water infrastructure.

Structure Durability

Climate change will impact the durability of a number of structures and materials. Among other things, it will increase stress on concrete, which affects roads, bridges and buildings, and it will increase stress on asphalt roads because of changes in the freeze-thaw cycle. The American Society for Testing and Materials has established standards for road concrete durability. These standards require that highway concrete remain durable through 300 freeze-thaw cycles. If climate projections can predict the changes in frequency of freeze-thaw cycles, then scientists can calculate the likely change in the useful life of concrete. The extent of these impacts requires further study.

Adaptation Strategies

The diversity of factors that contribute to climate impacts on public health and infrastructure lead to a wide range of possible strategies for adaptation. In keeping with the organizational framework presented in *Chapter 2: Understanding Adaptation*, we present

ADAPTATION

TAKING ACTION

Policy-makers should carefully weigh the impacts of their infrastructure investment decisions on human health and the state's capacity to adapt to a changing climate. For example, the health co-benefits of "green" transportation planning should be included in any cost-benefit analyses of adaptation to climate change.

Air Quality

Expand the Wisconsin Department of Transportation Congestion Mitigation and Air Quality grants to reduce the number of vehicle miles traveled and improve vehicle and fuel technologies to reduce vehicle emissions. Companies should reduce emissions of hazardous air pollutants to improve air quality and reduce ozone.

Human Health

Increase the urban tree canopy to reduce the urban heat island effect.

Water Infrastructure

Upgrade urban storm drains and best management practices based on continuous hydrologic modeling and climate predictions. Manage runoff to minimize high-flow impacts rather than sediment removal during high storm flows. Distribute management strategies throughout urban watersheds to mitigate high flows. Anticipate groundwater impacts on stormwater infiltration management practices.

Implement stormwater best management practices that will improve water quality while reducing sanitary sewer overflows. Increase capacity of municipal wastewater systems and minimize stormwater inflow and groundwater infiltration to prevent overflows. Require standby power for buildings with sump pumps to avoid system inflows caused by storm-related power outages.

Identify locations that are vulnerable to climate impacts and apply more stringent design criteria. Flood-proof vulnerable buildings and infrastructure.

Acquire land along waterways to prevent flooding, improve water quality and reduce sewer overflows.

Use low-impact design to minimize runoff from newly developed areas. Construct green roofs to improve water quality, reduce sewer overflows and improve building cooling.

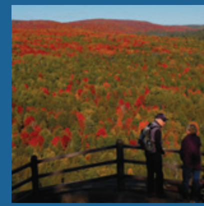
BUILDING CAPACITY

Expand the activities of the Wisconsin Environmental Public Health Tracking program to include indicators of air pollution conditions linked to climate variability and change. Establish a Vector-borne Disease Surveillance Program to collect data and assist in generating statistical reports and other epidemiological reports. Build capacity for drinking water quality emergency assessment and response.

Develop comprehensive transit strategies and explore alternatives for mass transit (for example, street cars, commuter rail, and high-speed rail) to improve air quality and reduce ozone.

The state should develop minimum design and performance standards for the control of the high-water impacts of development. In addition, it should:

- **Provide local units of government with the**



here several adaptation strategies relevant to public health and infrastructure in Wisconsin. (Please see the Human Health, Milwaukee and Stormwater Working Group reports at www.wicci.wisc.edu for a more detailed discussion of adaptation strategies.)

STRATEGIES

technical and financial assistance needed to assess and mitigate their vulnerabilities to potential high-water conditions caused by present and future climate conditions.

- Identify at-risk stream crossings and develop maintenance and high-water contingency plans.
- Periodically update estimates of high-water profiles based on revised rainfall data.
- Provide assistance to local governments for development of regional continuous hydrologic simulation models for both surface water and groundwater.
- Use updated models to predict groundwater impacts on development.
- Incorporate climate change considerations into watershed management and restoration plans.
- Revise building standards to address runoff volume control.

The Wisconsin Department of Natural Resources should develop an approval process for prior converted wetlands that are being removed from agricultural use to encourage their restoration and prevent development in flood-prone areas.

County and municipal governments should adopt an approval process for, or place land use controls on, development over hydric soils in areas that will experience future flooding.

Planners should coordinate with regulators to identify future land use changes and control land use around internally drained areas and over hydric soils and use updated models to predict groundwater impacts on development.

COMMUNICATING

Provide outreach and education on health impacts of air quality to county and city public health departments, school nurses, day care centers, summer camps, nursing homes and other facilities.

Educate communities about the hazards of building in areas prone to high water.

Coordinate with regulators to identify future land use changes and control land use around internally drained areas and over hydric soils.

Educate property owners about sanitary sewer inflow prevention.

FILLING THE GAPS

Improve and maintain Wisconsin's climate monitoring network (weather, stream flow, groundwater) to provide continued high-quality data to support short-and long-term climate impact modeling.

Invest in research at the state and national levels to build capacity and provide knowledge in the areas of winter-spring hydrology, hydrologic modeling and decision-making under uncertainty for water resource management.

Study the impact of increased precipitation on the frequency of combined and sanitary sewer overflows and water quality.

Research opportunities for mass transit such as street cars, commuter rail, and high-speed rail to improve air quality and reduce ozone.

ADAPTATION IN ACTION: GREEN INFRASTRUCTURE

When it rains, the water running off roofs, driveways, parking lots and streets picks up pollutants along the way. Currently, much of this untreated runoff is directed through culverts and storm sewers to the state's streams, rivers, and lakes. But there is a better, more sustainable way to work *with* nature in managing stormwater. Green infrastructure can help reestablish natural hydrologic cycles through an integrated system of natural areas and constructed elements ranging from restored riparian corridors to "green" streets, parking lots, and roofs. Green infrastructure reduces stormwater runoff volumes and slows rates of discharge by using the natural retention and absorption capabilities of vegetation and soils. This approach to managing wet weather also uses plants and soil microorganisms to break down many of the pollutants found in runoff.

DESIGN PRINCIPLES

Natural landscape features such as forests, floodplains and wetlands are critical components of green infrastructure. By protecting these ecologically important areas, communities can improve air and water quality while also providing plant and wildlife habitat, scenic beauty, and opportunities for outdoor recreation. Green infrastructure also includes smaller features such as rain gardens, porous pavements and bioswales within parking lots, and green roofs. These technologies can reduce flooding and sewer overflow events and help prevent pollutants from being transported to nearby surface waters. Green infrastructure is especially cost-effective when it is strategically designed to yield multiple functions that have ecological, economic and social benefits.

MULTIPLE BENEFITS

Green infrastructure can make communities more livable and enhance property values. The benefits of green infrastructure increase in urban and suburban areas where green space is limited and impervious surfaces are more extensive. Urban heat islands form when natural land cover is replaced with dense concentrations of pavement, buildings and other surfaces that absorb and retain heat. By increasing urban green space and trees, green infrastructure can lower the demand for air conditioning, thereby reducing both energy consumption and air pollutants emitted from power plants. Recent research has linked the presence of trees and green space to reduced levels of inner-city crime and violence, improved academic performance, increased physical activity and reduced childhood obesity.

Conclusion

Current threats to public health will likely worsen in the face of climate change. With projections for more days with temperatures greater than 90º F, heat waves will likely occur more frequently, more intensely, and they will last longer. Air pollution including smog, particle pollution and airborne allergens will worsen. Waterborne diseases may increase as heavy rainfall events occur more frequently, and vector-borne disease transmission will be affected as climate change alters the habitat conditions of the disease carriers.

Our climate is changing at a pace more rapid than it has historically, and current infrastructure designs will likely prove inadequate over the next century. The infrastructure of our cities, towns and transportation systems has been designed based on historical weather and climate data. We need to design, build and manage our built environment with future climate projections in mind to reduce the risks of stormwater runoff and flooding and to protect our drinking water, wastewater systems and infrastructure durability. For human health and the built environment, "business as usual" is not adequate to manage current and future risks posed by climate change to society.

Source material for this chapter was drawn from the Human Health, Milwaukee, and Stormwater Working Group reports, available online at www.wicci.wisc.edu.

Photo: The Kubala Washatko Architects, Inc./Mark F. Heffron

Photo: Courtesy of Finn Ryan and Climate Wisconsin

Photo: William Walker

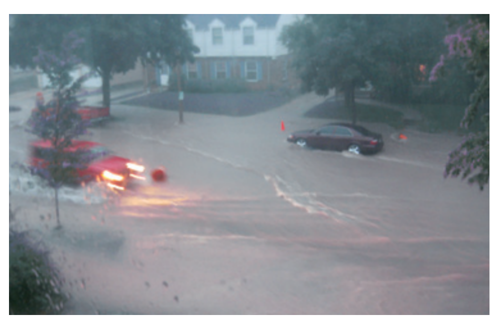


Photo: Sandra McLellan

PART 3:

ACTION

CHAPTER EIGHT
IMPLEMENTING

Principles for Adaptation

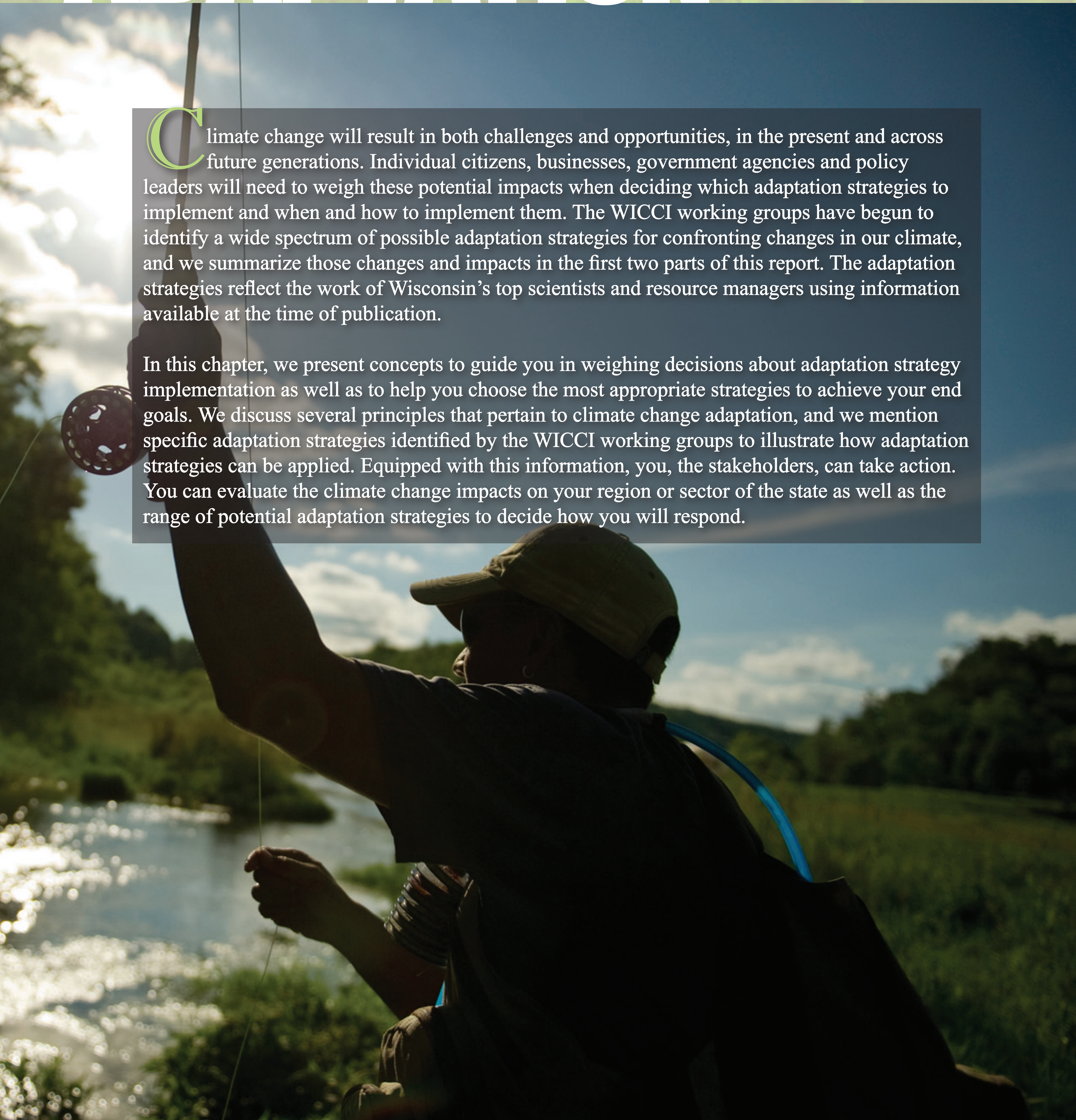
The Road to Implementation

Photo: Courtesy of David Nevala and Climate Wisconsin

ADAPTATION

Climate change will result in both challenges and opportunities, in the present and across future generations. Individual citizens, businesses, government agencies and policy leaders will need to weigh these potential impacts when deciding which adaptation strategies to implement and when and how to implement them. The WICCI working groups have begun to identify a wide spectrum of possible adaptation strategies for confronting changes in our climate, and we summarize those changes and impacts in the first two parts of this report. The adaptation strategies reflect the work of Wisconsin's top scientists and resource managers using information available at the time of publication.

In this chapter, we present concepts to guide you in weighing decisions about adaptation strategy implementation as well as to help you choose the most appropriate strategies to achieve your end goals. We discuss several principles that pertain to climate change adaptation, and we mention specific adaptation strategies identified by the WICCI working groups to illustrate how adaptation strategies can be applied. Equipped with this information, you, the stakeholders, can take action. You can evaluate the climate change impacts on your region or sector of the state as well as the range of potential adaptation strategies to decide how you will respond.



Principles for Adaptation

Here we provide several principles for you to consider when making decisions about climate change adaptation and determining which actions are feasible to take now, later or not at all. Our intention is for these concepts to provide you with perspective in decision-making and guidance for implementation of appropriate adaptive actions.

Triage Approach

Determine which actions to implement first. The concept of triage involves directing resources to the issues and areas where strategic adaptation will be most effective. Adaptation can help us reduce risks and minimize impacts caused by climate change. We cannot, however, eliminate all risks and losses, even if we implement the most appropriate strategies. In some cases, investments in adaptation are unlikely to have significant returns. In other cases, effects of climate change will pose little risk and thus require nothing new to be implemented. Stakeholders will need to consider the value of possible adaptation strategies based on the vulnerability of a particular resource and the likelihood that a specific action will successfully address an identified concern. This triage approach will allow you to target limited resources most efficiently.

Adaptive Management

Build flexibility into management practices. Adaptive management offers a tool to help stakeholders

Photo: Darren Bush

make better decisions in the context of uncertainty as we continue to accumulate more information. Often characterized as "learning as we go" or "learning by doing," adaptive management provides a structured, iterative, decision-making process that can be used in the face of uncertainty with an aim of reducing that uncertainty over time. This approach involves ongoing, real-time learning and knowledge creation, both in a substantive sense and in terms of the adaptive process itself. The approach allows you to maintain **flexibility** in your decisions, knowing that uncertainties exist, and provides the latitude to change direction. In this way, decision-making can simultaneously maximize one or more resource objectives and, either passively or actively, accrue information needed to improve future management. Using adaptive management approaches will allow us to take **action** to improve progress towards desired outcomes. Such approaches also allow for new climate information to be incorporated as we move forward.

"No Regrets" Strategies

Choose strategies that increase resilience and provide benefits across all future climate scenarios. Implementation of some strategies will result in environmental or societal benefits no matter how the climate changes. We refer to these strategies as having no regrets. For example, protecting environmentally sensitive lands, encouraging water conservation and implementing polluted runoff controls makes sense under any climate scenario. These actions can build resilience without necessarily committing stakeholders and resources to novel future courses of action. We believe some of the best adaptation strategies will allow us to prepare for climate change by taking action now in ways that will not make adaptation in the future more difficult. The WICCI working groups identified actions that are intended to provide net environmental and social benefits under all future scenarios of climate change and impacts.

Precautionary Principle

Where vulnerability is high, it is better to be safe than sorry. Sometimes if we wait for certainty it is too late. The 1992 Earth Summit in Rio de Janiero proposed, "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." Given the breadth of likely climate change impacts in Wisconsin and the associated risks to the public and environment, we believe a precautionary approach should be taken by stakeholders even if some cause-and-effect relationships are not yet fully understood. Cases where the probability of risk is low but the vulnerability is very high suggest precautionary action should be taken. These "better safe than sorry" strategies can be modified later if new information suggests that no or minimal harm will result from a climate impact. The process of applying this precautionary principle must be open, informed and democratic and must include potentially affected parties. It must also involve an examination of the full range of alternatives, including taking no action.

Adapting to Variability in a Changing Climate

Expect variability and work within it. Wisconsin's climate will continue to be highly variable across years and decades. Even though average temperatures have warmed and are projected to warm, and average

precipitation has increased and is projected to increase, there will still be unusually warm and cool years and unusually wet and dry years in the mix. It is essential to understand this variability in order to successfully implement adaptation strategies. For example, if brook trout disappear from a stream after a few unusually warm years, it may be possible to restock them to provide good fishing for a few cooler years before long-term warming trends cause them to die out again. If we had the ability to accurately project temperature variability between warm and cool over periods of a few years, our ability to manage threatened resources would be improved. The same logic is true for the operation of winter recreation facilities, crop-planting decisions and much of the annual planning done by individuals and groups. This highlights the need to improve our science: As we continue to monitor and better understand variability, we can continue to improve strategies for adapting.

Place-Based Considerations

Consider the restrictions and special circumstances of place-based impacts. Adaptation to climate change is important because our human and natural systems are fixed in location. All of Wisconsin's human and natural systems are "place-based" (for example, individual farms, municipalities, lakes and natural areas) and we know that climate change impacts vary spatially. We will need to consider these spatial relationships when adopting adaptation strategies. For example, climate change will affect the distribution of culturally important resources such as wild rice and walleye, but some of the Native American tribes who rely on these resources may not be able to follow those shifts in ranges because their reservation boundaries and off-reservation treaty rights are geographically fixed. People may – at a cost – decide to move out of a floodplain as floods become more prevalent, but industries and agriculture and their institutions are tied to place and will have to deal with the changing climate and its impacts. Place-conscious planning and place-based strategies can leverage our investments by focusing resources in targeted places and compounding the effects of well-coordinated action. Such approaches can also streamline otherwise redundant and disconnected programs.

Adaptation Complements Mitigation

Recognize the place of adaptation in the bigger picture. Adapting to climate change impacts is not a substitute for mitigation – the reduction of the rate at which greenhouse gases are emitted into the atmosphere. We can implement adaptation strategies that help us adjust to and thrive in our natural and built environments as they are affected by climate change impacts at the same time as mitigation efforts are being enacted. The two goals can be pursued simultaneously, and in some cases, an adaptation strategy can achieve both adaptation and mitigation. For example, in Chapter 7: *People and Their Environment*, working groups suggest the need for programs and research on mass transit and vehicle technologies to both improve air quality and reduce ozone and greenhouse gases. We support and encourage the development and implementation of strategies that provide these co-benefits. As people better understand the impacts of climate change and how it affects air and water quality, our food systems and public health, they are likely to become more active in mitigation measures that address climate change at broader scales.

The Road to Implementation

Now that we have reviewed the main principles of adaptation, we turn to some specific adaptation strategies that WICCI working groups have recommended in order to highlight *toward what end* these actions work. We present the discussion here, consistent with the framework laid out in Chapter 2: *Understanding Adaptation* and the Adaptation Strategies boxes throughout the chapters in Part 2: *Impacts*. These examples generally illustrate ways in which adaptation strategies can address the climate change impacts on multiple resources. Readers can refer to the full working group reports (available at www.wicci.wisc.edu) for adaptation strategies for specific resources or locations.

In order to reduce risks from climate change, adaptation will require decisions that acknowledge both space and time. To be effective, some strategies will need to be implemented on a broad scale (statewide), while other actions can be implemented at a particular place (local or site-based). Similarly, some adaptation strategies can be implemented in the short term, but others will require planning and preparation that extend well into the future.

Taking Action

The "taking action" strategies include natural systems management choices, social systems improvements and infrastructure modifications. They allow us to manage risks effectively in the face of uncertainties. These actions generally fall into two categories. The first type relates to undertaking activities that could offset some of the negative impacts of climate change on specific resources. The second type relates to better directing management efforts and resources to locations where the actions will provide the greatest benefit. Some adaptation strategies involve doing both of these things. These types of strategies can occur at any level and do not require us to wait for federal or state governments to take action.

Implementing adaptation on a broad scale. Protecting environmentally sensitive agricultural lands by enrolling them in the Conservation Reserve Program (CRP) or similar federal or state programs could help offset some negative climate change impacts. By targeting such conservation efforts to specific areas, we can provide even greater benefits. The Coldwater Fish and Fisheries Working Group identified setting aside land in this manner as a potential adaptation strategy for coldwater streams. Maintaining native vegetation on such lands would help maintain water temperatures and prevent soil losses. The working group recommended a "triage" strategy of allocating limited resources to streams where this type of effort can delay the loss of trout. This "no regrets" strategy could help in reversing the loss of wetlands and restoring prior converted wetlands to provide storage and filtration capacity as recommended by the Water Resources and Green Bay Working Groups. This "precautionary" approach also would reduce erosion from intense rainfall events as suggested by the Soil Conservation and Stormwater Working Groups. Finally, this approach could help establish and maintain corridors of contiguous natural vegetation, an adaptation strategy identified by the Plants and Natural Communities and Green Bay Working Groups.

Adapting at the local level: building urban green infrastructure. Increasing green space in our urban communities is an adaptation strategy identified by a number of WICCI working groups. Integrating green infrastructure (open space, green roofs, tree canopy, etc.) into planning and development can reduce both stormwater runoff and heat island effects. These

actions help build resilience. As noted by the Milwaukee and Stormwater Working Groups, green infrastructure can also help reduce combined sanitary sewer overflows and prevent flooding.

To maximize the multiple potential benefits of green infrastructure, a regional perspective could facilitate cooperation among local jurisdictions. For example, Wisconsin's regional planning commissions have regional planning mandates and relatively long planning horizons:

"The Southeast Regional Planning Commission (SEWRPC) was created in 1960 to provide the basic information and planning services necessary to solve problems which transcend the corporate boundaries and fiscal capabilities of the local units of government comprising the Southeastern Wisconsin Region. For fifty years SEWRPC has provided such information and planning services needed to solve problems and provide focus and attention on key issues of regional consequence."

Building Capacity

The WICCI working groups identified a number of adaptation strategies that involve creating a better understanding of climate science, impacts and adaptation strategies along with tools for resource managers and other decision-makers. These "building capacity" strategies include conducting applied scientific research, developing local modeling and management frameworks, implementing new management techniques at the local and program level and training and educating natural resource managers and others to use new tools.

Supporting Wisconsin's State Climatologist. The Wisconsin State Climatology Office, affiliated with the UW-Madison's Department of Atmospheric and Oceanic Sciences, manages data for climate monitoring, provides climate information to Wisconsin residents and government agencies, develops "value-added" products for users and impact applications and conducts applied climate research. We recognize the

Photo: Callen Harty

Photo: William Walker

Photo: Callen Harty

Photo: Elizabeth Katt-Reinders

importance of additional state funding and continued support the State Climatology Office.

A framework for local government planning. Working with the Wisconsin Towns Association, League of Wisconsin Municipalities, regional planning commissions and other local government associations, the WICCI working groups can expand efforts to help communities integrate climate adaptation strategies into local community planning activities. Communities can have greater confidence in their emergency management and hazard mitigation plans if they consider climate change impacts and the associated vulnerabilities. Similarly, land use and development plans that factor climate change scenarios into their future projections will better serve communities in guiding future development patterns. Along these lines, the Coastal Communities, Water Resources and Green Bay Working Groups suggested that communities may want to re-examine ordinances and wetland and shoreland management programs to be sure that they make sense given a likely increase in bluff recession rate, fluctuations in water levels and increasing frequency of extreme events. Communities should create or update comprehensive plans and periodically revisit and revise these plans and implement ordinances, as needed. This "precautionary" approach also could help reduce erosion from intense rainfall events as suggested by the Soil Conservation and Stormwater Working Groups.

Short-term solutions: new species management techniques. There will always be variability in climate and climate change impacts. We can best manage variability by understanding the tradeoffs it presents. For example, fisheries managers will need to respond to changes in stream water temperatures. In warmer years, managers may want to substitute brown trout for brook trout in their stocking programs because brown trout are slightly more tolerant of warmer water. Alternatively, these managers could use a "put-and-take" approach for cold months that provides short-term angling opportunities while acknowledging that the brook trout will die off in a near-future summer.

Communicating

The WICCI working groups identified a number of adaptation strategies related to articulating the risk from future climate and the need for polices and planning that will maintain society's flexibility for adapting to new and future impacts. These "communicating" adaptation strategies include dialog with the public, decision-makers, community groups, local governments, nonprofits and others about impacts from climate change and the benefits of adaptation.

Short-term adaptations: informing the public of risks. Implementation of some strategies will result in benefits regardless of how climate changes. For example, public protection authorities (county sheriffs, conservation wardens, etc.) and weather news personnel may want to consider providing short-term risk advice on issues including thin-ice hazards on lakes or heat-related health risks.

Broad-scale adaptation: informing public officials. Working with UW-Extension, Sea Grant and other educational organizations, the WICCI working groups can expand efforts to provide local governments with information about climate science, projected impacts, types of adaptation strategies and means of implementing those strategies. Enhanced communication will be particularly important in cases where the probability of risk is low but the vulnerability is very high and "better safe than sorry" measures could significantly offset possible impacts. This could include efforts to educate communities about the hazards of building in areas prone to high water or coastal erosion, as recommended by the Coastal Communities, Water Resources and Stormwater Working Groups, or about ways to minimize sanitary sewer overflows, as noted by the Coastal Communities, Stormwater and Milwaukee Working Groups.

WHAT IS A COMPREHENSIVE PLAN?

A comprehensive plan is a local government's guide to community physical, social and economic development. Comprehensive plans are not meant to serve as land use regulations in themselves; instead, they provide a rational basis for local land use decisions with a 20-year vision for future planning and community decisions.

The Wisconsin Comprehensive Planning Law does not mandate how a local community should grow, but it requires public participation at the local level in developing a vision for the community's future. The uniqueness of individual comprehensive plans reflects community-specific and locally driven planning processes.

While a local government may choose to include additional elements, a comprehensive plan must include at least all of the nine elements below, as defined by the Comprehensive Planning Law.

- **Issues and Opportunities**
- **Housing***
- **Transportation***
- **Utilities and Community Facilities***
- **Agricultural, Natural and Cultural Resources***
- **Economic Development***
- **Intergovernmental Cooperation**
- **Land Use***
- **Implementation**

*** elements affected by climate**

Element Guides are available online at www.doa.state.wi.us.

Filling Gaps

The WICCI working groups identified a number of adaptation strategies that involve expanding our knowledge about how natural and human systems will respond to climate change. "Filling gaps" includes basic scientific research, establishing data-gathering programs, improving climate modeling and learning from climate adaptation efforts in other states. While much of this work will fall to the University and state agencies, there is room for many other players to be involved in defining information needs and helping ensure that research and monitoring improve our ability to assess risk and proactively adapt.

WICCI's next report. In this report the working groups assessed vulnerabilities and suggested adaptation strategies using currently available information and resources. An important part of filling the gaps will be recruiting additional participants for WICCI working groups to respond to emerging knowledge that results from ongoing research and new scientific discoveries. Additional working groups will be needed to address new focus areas. We expect to produce our next report in about four years.

Preparing for adaptive management: broad-scale monitoring. In order to recognize the reality of variability in climate and adapt accordingly, we will need to understand how variability manifests itself in future climate scenarios and how it is reflected in natural processes and human systems. Adaptive approaches that allow new information to be incorporated as we move forward will increase our flexibility in how we respond to changes. Along these lines, several working groups recommended instituting better, more robust climate monitoring programs. For example, the Wisconsin Department of Natural Resources and University of Wisconsin can work with federal, state and local partners (for example, the National Oceanic and Atmospheric Administration, U.S. Geological Survey, local public works and public health departments) to support a network of monitoring stations for collecting important observations. These include systems to measure rainfall, stream flows and water levels as well as surveillance programs for harmful algal blooms and beach pathogen outbreaks. As noted by the Forestry and Agriculture Working Groups, climate science that increases the certainty around precipitation trends and patterns will assist us in better impact modeling. Similarly, the Stormwater Working Group found that improving and maintaining Wisconsin's climate monitoring network would provide continued high-quality data to support short- and long-term impact modeling. The Human Health Working Group noted the importance of the Wisconsin Pubic Health Tracking Program for tracking indicators of air pollution that may be affected by climate change.

Preparing for adaptive management: species- and community-specific assessments. Resources remain insufficient to address all possible threats. To help reduce the uncertainty in making decisions about resource allocations, both the Plants and Natural Communities and Wildlife Working Groups recommended that risk assessments be made based on impact predictions for individual species and natural communities. Similarly, the Green Bay Working Group identified a number of species and community-specific information needs. These assessments could be used in prioritizing adaptation actions. As climate scientists improve global climate models and refine downscaling results, we will have more and better data on which to base such assessments.

A more complete discussion of climate adaptation can be found in the WICCI Adaptation Working Group report, available online at www.wicci.wisc.edu.

Conclusion

Climate change is a complex phenomenon with impacts on every sector of our lives. As you, the stakeholder, assess the information presented in this report and consider your options for taking action, the principles outlined in this chapter can guide your decision-making and implementation. These principles can help you consider which actions to implement first, the degree to which flexibility can be built into resource management practices and whether some strategies will bring benefits regardless of how the climate continues to change. They suggest that when vulnerability is high, it may be a better strategy to be safe rather than sorry; they remind that variability is a reality to be recognized and that some place-based impacts present unique restrictions and circumstances for adaptation. Lastly, these principles include a call for a big-picture view of adaptation, recognizing that adaptation strategies can and should be implemented alongside mitigation efforts.

This report presents a wide range of strategies for you to consider as you chart your adaptation course. You may implement these strategies to work towards a variety of goals, including taking action to confront climate impacts; building capacity for understanding climate science, impacts and adaptation; communicating the challenges and opportunities brought on by climate change; and filling the gaps in our scientific and management knowledge. This report is the first step on a long road of strategic climate adaptation in Wisconsin. The next step is yours.

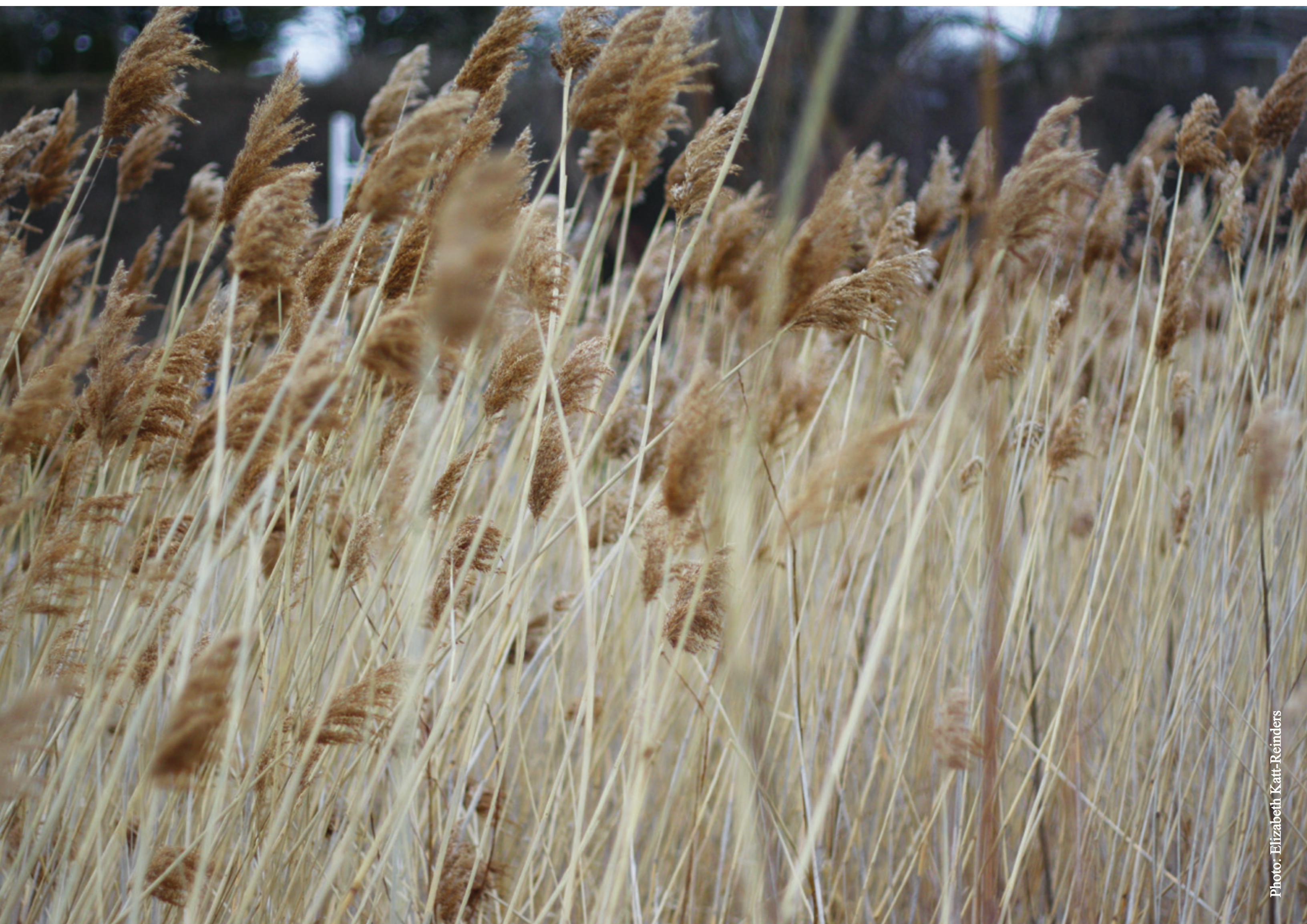


Photo: Elizabeth Katt-Reinders

Ongoing Research

Future Areas of Focus

Outreach and Communication

Photo: Darren Bush

CHAPTER NINE

MOVING FORWARD

This report is the first of what will be a recurrent assessment of climate change impacts and adaptation strategies in Wisconsin. Even as we synthesized the findings of the working groups, those working groups continued to move forward with their vulnerability assessments and identification of possible adaptation strategies. In this chapter we highlight ongoing climate and adaptation research efforts, describe areas in need of future attention and present an outreach strategy for communicating the results of the current WICCI effort.

Ongoing Research

This first assessment report reflects the current state of the science on climate change in Wisconsin at the time of publication. We recognize that science progresses and new discoveries are continually being made. In this section we outline significant ongoing work associated with the WICCI working groups. Future WICCI efforts, including future impact and assessment reports, will benefit from these Wisconsin-based studies. We acknowledge, however, that as our understanding of climate change evolves and new information is obtained – some of which may appear to conflict with previous data – we will need to build close relationships between policy-makers, managers and scientists as a way of integrating new knowledge into future impact and vulnerability assessments and adaptation strategies.

Downscaled Climate Data for the Upper Midwest and Great Lakes

With support from the U.S. Fish and Wildlife Service and Environmental Protection Agency, researchers at the University of Wisconsin-Madison Nelson Institute Center for Climatic Research are extending downscaled temperature and precipitation (including snow cover) projections for Wisconsin to the Great Lakes region. These Great Lakes climate projections will be coordinated with similar projections that are being developed for the plains and prairie potholes region. Since the models employed in the projections will be downscaled from a suite of national models, these projects could establish a standard for a national system of downscaling.

Photo: Elizabeth Katt-Reinders

Downscaled Wind and Other Climatological Parameters

Researchers at the UW-Madison Nelson Institute Center for Climatic Research are downscaling additional climatological parameters of relevance to energy production in the state. With support from Wisconsin's Focus on Energy program, the team has identified additional variables that will help us better understand future impacts, including wind (alternative energy production, lake mixing, coastal processes), humidity (human health, evapotranspiration, hydrology), evapotranspiration (lake levels, ecosystems, hydrology) and solar radiation (human health, lake stratification).

Hydrologic Impact Modeling

With support from Wisconsin's Focus on Energy program, researchers at the Wisconsin Department of Natural Resources are assessing the long-term hydrologic impacts of climate change across Wisconsin. Ten-year average annual runoff and nonpoint source pollutant loadings will be modeled for approximately 1,700 sub-watersheds and 50,000 stream catchments. Models will be built and run for the period between 1950 and 2006 using daily precipitation data developed by WICCI partners. Runoff and pollutant loadings will be calculated under multiple future climate and land use scenarios using downscaled global climate model precipitation data created by WICCI partners for the period between 2046 and 2055.

Photo: Bob Korth

Lake Superior Carbon Balance

The Ocean Biogeochemistry Research Group affiliated with the UW-Madison Nelson Institute Center for Climatic Research is leading a project to understand the carbon balance of Lake Superior. This team is working to understand the lakewide carbon budget and the processes controlling its variability using numerical models and data. This work includes evaluating the impact of lake-to-air carbon dioxide fluxes on atmospheric carbon dioxide, work on analytical techniques, adding biogeochemical inputs from major rivers to the existing model, and evaluating inversion algorithms for biogeochemical properties.

Fluxes of Carbon and Water in Lakes and Wetlands

Researchers at the Wisconsin DNR are working to better understand fluxes of water and carbon in northern Wisconsin lakes and wetlands. With support from Wisconsin's Focus on Energy program, this team has developed new technologies that allow us to remotely monitor the short- and long-term effects of rainfall and drought on water fluxes. They will now link these technologies with methods developed by UW-Madison limnologists to remotely monitor internal carbon fluxes in lakes over similar time scales. The team will also explore technologies to monitor carbon fluxes between lakes and their adjoining wetlands. Data from this study can be used to enhance models of the regional carbon cycle.

Climate Analogs and Potential Shifts in Forest Composition and Extent

Researchers at the UW-Madison Nelson Institute Center for Climatic Research are using funding from Wisconsin's Focus on Energy program to identify the closest analogs between 21st century projected climates for Wisconsin and existing climates in the U.S. and Canada. The results will provide policy-makers with examples of current landscapes that may be the closest parallels for what Wisconsin will become over this century. The team will also model the likelihood of prairie encroachment into southern Wisconsin forests and the likelihood of invasion of non-native tree species. This work relies on the previously downscaled climate data generated by WICCI partners.

Carbon Fluxes and Climate Change Impacts from Forest Land Management

Photo: Avery Dorland

Researchers at the UW-Madison's Department of Atmospheric and Oceanic Sciences are working to quantify the flux of carbon in Wisconsin forests undergoing land management. The primary objective of their study is to understand how land management alters the carbon cycle for forest ecosystems and investigate how well we can predict carbon cycle impacts of differing land management scenarios. The study will measure pre-, during and post-harvest carbon fluxes in a hardwood forest, analyze the impact of this management on carbon fluxes and compare the findings to a state-of-the-art landscape ecosystem model.

Climate-Vulnerable Terrestrial Species and Natural Communities

Researchers have developed a climate change sensitivity database for terrestrial species in our region. This database includes life history characteristics for 463 species and provides an initial screening tool for assessing impacts on these species. With support from the U.S. Fish and Wildlife Service, researchers will integrate outputs from the database with those of selected national/regional climate change vulnerability assessments. The findings, including indices of scientific knowledge and management expenditures for each species, will be presented to government entities across the Upper Midwest. State and regional working groups will identify common management objectives, evaluate the results of the screening process, and identify 30-50 terrestrial species for further detailed evaluation.

Photo: A.B. Sheldon

Identifying Key Vulnerabilities for Birds and Mammals

Photo: Callen Harty

Researchers at the UW-Madison departments of Botany and Forest and Wildlife Ecology are conducting a thorough review of northern Wisconsin paleorecords (pollen assemblages), research on contemporary ecological processes and regional and local climate/biotic response models. From this review, they will identify terrestrial habitat and species vulnerabilities and make management recommendations. This work includes 1) collection and analysis of new sedimentary pollen records in habitats of concern and in landscapes with poor representation, 2) analysis of existing sedimentary records – finding locations with different rates of vegetation change and reinterpreting existing sedimentary records and 3) explaining stability and variability of natural communities.

Climate Adaptation Recommendations for Site Managers

With support from the U.S. Fish and Wildlife Service, WDNR researchers are assessing tradeoffs between mitigation and adaptation strategies within sub-regions of the Great Lakes region. They will conduct a literature review for climate mitigation and adaptation options for natural resource managers. Agencies will be interviewed for additional detail on management options and the management tools they use. Tradeoffs between multiple scenarios of mitigation and/or adaptation strategies will be analyzed. Mitigation and adaptation options will be classified by their compatibility with each other and existing management priorities. A follow-up project will identify the most climate-resilient lands in the Great Lakes basin, such as places where adaptation planning for resilience is most likely to succeed.

Climate Change, Shifting Land Use and Urbanization

Researchers at the UW-Madison are using integrated scenarios and model experiments to assess effects of changing drivers on 1) human benefits derived from ecosystems, 2) evaluations of governance, 3) public engagement and 4) information management. The focus is the Yahara River watershed, where they will address three questions: 1) How do different patterns of land cover, land management and water resource engineering practices affect the resilience of freshwater ecosystems under a changing climate? 2) How can governance systems for water and land use be made more responsive to drivers of change to meet diverse human needs? 3) In what ways are human-environment systems able to cope with change, and in what ways are they vulnerable to potential changes in climate and freshwaters?

Climate Change Impacts on Warmwater Fishes

Researchers at the WDNR are expanding efforts to assess the impacts of climate change on fish communities. As a follow-up to the WICCI Coldwater Fish and Fisheries Working Group's initial efforts, scientists are now modeling potential impacts on additional coldwater fish species as well as changes in warmwater systems and predicting impacts on species typical of these habitats.

Future Areas of Focus

Although broad and comprehensive in our approach, we were not able to predict impacts, assess vulnerabilities or suggest adaptation strategies for all of Wisconsin's natural resources and sectors in this first report. Below, we highlight several areas that merit additional attention. We hope to address these areas in future phases of the WICCI effort and include vulnerability assessments and adaptation strategies in follow-up reports.

Great Lakes

Scientists already have observed record warmth in both lakes Superior and Michigan. The effects of warmer water on the lakes' fisheries remain in question. Scientists are also working to understand potential changes in water chemistry and lake levels.

Mississippi River

Changes in precipitation will result in changes in surface water runoff and groundwater recharge throughout the Mississippi's watershed. The effects of these changes have not yet been studied because downscaled climate models do not yet cover the entire basin, most of which lies outside of Wisconsin. A downscaled climate model for the Upper Mississippi River watershed (above the confluence with the Missouri River) is needed to make predictions regarding physical effects of climate change on the main stem of the river.

Groundwater

Changes in precipitation patterns and soil moisture will affect groundwater recharge. How these changes might impact drinking water quality, irrigation, discharges to lakes and wetlands or other characteristics of groundwater resources has yet to be investigated.

Air Quality

Climate governs several of the natural processes that influence air quality. Scientists and regulators will need to consider how climate change might impact Wisconsin's overall ability to meet air quality standards.

Agriculture

While we discussed climate change impacts on Wisconsin's corn and soybean crops, we have yet to assess the vulnerabilities of the rest of our agricultural commodities, for example, heat stress impacts on dairy cattle production or air quality impacts on crop yields.

Water Use and Availability

Future demands for water – including residential, agricultural and industrial water uses – due to increased temperatures, potential modifications of cropping practices and extended periods of drought may stress already limited aquifer resources in some areas and put more pressure on surface waters and the Great Lakes as a water source. We need to better understand the implications of future water supply and demand issues in the context of climate change.

Energy Utilities

Discussions about the energy sector and climate change often focus on utilities as a source of carbon dioxide emissions. It also is important to consider how a changing climate affects the ability of utilities to power Wisconsin homes and businesses.

Biomass

Biomass represents a significant renewable energy resource. Agricultural biomass may be impacted by changes in food-crop residue and growth rates and yields of crops produced specifically for energy production.

Transportation

The National Research Council recently concluded that every mode of transportation will be affected as the climate changes. We will need to identify critical infrastructure that is particularly vulnerable and make more strategic, risk-based decisions in our transportation planning.

Tourism

Climate contributes to the suitability of locations for many tourist activities. It also is a principal driver of seasonality in tourism demand. Changes in climate will require adaptation by tourism stakeholders to ensure tourism's continued vitality.

Loss of Winter as We Know It

Winter contributes to our "sense of place." Our culture, music and activities (ice skating, downhill and cross-country skiing, sledding, snowboarding, ice fishing, snowmobiling) recognize this portion of our four seasons. Economies in parts of our state depend on the ability to provide winter amenities. We are slowly losing winter as we know it, and this trend is very likely to continue – meaning that winter features will be degraded or lost, resulting in both aesthetic and economic consequences.

Community Planning

It is largely at the local government level where many adaptation actions will be needed, discussed, agreed to, prioritized and implemented. Wisconsin's communities will need to consider how climate adaptation measures can be integrated into plans, ordinances and related policies.

Economics, Policy Implementation and Social Systems Considerations

We must begin identifying our capacity to plan and sustain long-term efforts to adapt to our changing climate. Stakeholders will want to analyze both the positive and negative economic impacts of a changing climate as well as the tradeoffs associated with specific adaptation measures.

Outreach and Communication

If Wisconsin is to successfully adapt to current and future climate change, information about climate science, predicted impacts, types of adaptation strategies and means of implementing those strategies must reach local and state decision-makers. The Wisconsin Initiative on Climate Change Impacts has been well-designed to perform climate modeling scaled to our state (Chapter 1), identify likely impacts from future conditions (Chapters 3-7), suggest adaptation strategies and highlight gaps in knowledge and capacity for climate adaptation. WICCI itself, however, lacks the capacity to make a comprehensive statewide effort to bring this information to the people who need it. Furthermore, the time scale of climate adaptation (years to decades) is beyond the likely organizational lifespan of WICCI. Consequently, WICCI envisions a climate adaptation outreach model that:

- Supports natural- and human-system managers and other decision-makers in assessing vulnerabilities and evaluating risks from climate impacts.
- Continues to engage Wisconsin academic institutions, state agencies, professional associations and other organizations in a process of identifying adaptation strategies.
- Provides general information on climate risk and adaptation to communities to support implementation of climate adaptation.
- Builds a foundation for long-term integration of climate risk education into Wisconsin's professional and community development efforts.

Photo: Darren Bush

To meet these objectives, WICCI will collaborate with existing education providers and support integration of WICCI information into existing and new outreach programs. These providers include:

- Professional organizations that have participated in WICCI working groups.
- Member organizations of the WICCI Advisory Committee (for example, Wisconsin Towns Association, League of Wisconsin Municipalities, etc.).
- Professional organizations that have participated in WICCI working groups.
- State outreach programs in the departments of Natural Resources, Health Services, etc.
- Outreach education programs through UW-Extension.
- Non-governmental education providers.

Delivery of WICCI outreach education will encompass many modes of learning:

- WICCI will provide speakers and prepared presentations on climate adaptation for delivery to organizations and communities.
- WICCI will sponsor ongoing workshops for other outreach education providers to update them on climate information and outreach methods.
- The WICCI Web site will be maintained as an accessible source of current, reliable information on climate adaptation strategies and outreach tools.
- The WICCI series of assessment reports will continually update knowledge about climate prediction, vulnerabilities and adaptation strategies.

Photo: William Walker

APPENDIX

AGRICULTURE WORKING GROUP

Both farmers and agricultural policy-makers need information about how climate change will affect agriculture. For growers and agribusiness to respond to market and policy incentives on energy crops, they will need to understand the long-term viability of their investments in the face of shifting climate conditions. The programs of state and federal agriculture and energy agencies will be more efficient and effective if we know what kind and how much biomass a given region can produce under average and extreme conditions in the future. A grand challenge confronting agriculture is to better understand how cropping systems and farmers have responded to changes in the climate system and whether future climate change and increasing atmospheric CO_2 may make agro-ecosystems more vulnerable to failure. Climate change and increased variability pose a real threat to the stability of agro-ecosystems in the long term, jeopardizing food and economic security. While many studies have demonstrated the sensitivity of cropping systems to climate, no consensus has yet emerged regarding the specific mechanisms responsible for causing such changes or how these play out in specific regions. This makes it virtually impossible to implement local policies to protect agricultural lands.

Wisconsin is considered one of the nation's leading and most diverse agricultural producers, generating approximately $51 billion in economic activity while relying on 44 percent of the total land area in the state. The combination of a suitable climate and fertile soils allows farming to be one of the mainstays of the Wisconsin economy, and with a new focus on producing renewable energy crops, additional value will be placed on the agricultural land base. Consider the following facts taken from the Wisconsin Working Lands Initiative:

- Agriculture is responsible for a direct economic impact of $22.3 billion annually, which tops forestry ($22.1 billion) and tourism ($11.9 billion).

- Agriculture provides a diversity of ecosystem goods and services that enhance the economy and improve the quality of life.

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- Agriculture supports growth of a bioeconomy through growing biomass that can be used for fuel (for example, ethanol) and other products, thereby decreasing our dependence on fossil fuels.

Protecting agriculture provides security for the future: production of food and fiber for humans and animals within the region if transportation systems cannot deliver a sustained supply from abroad.

The importance of Wisconsin agriculture is further reflected in the fact that there are approximately 78,000 farms in Wisconsin that had cash receipts in 2008 totaling $9.89 billion, of which approximately two-thirds came from livestock, dairy, and poultry. Row crops (such as corn and soybeans) and vegetable and horticultural crops made up much of the remainder. Our agricultural systems occupy a little more than 15 million of the approximately 42 million acres in the state, although the average size of a farm is only a modest 194 acres.

As would be expected, the Dairy State ranks first nationally in cheese production and second in milk and butter production. Yet Wisconsin is also second in milk cows, oats, carrots, and sweet corn used in processing. We remain the national leader in processed snap beans, cranberries, corn for silage, mink pelts and milk goats. We are also among the top five states for important agricultural commodities such as potatoes, maple syrup, mint for oil, and cucumbers for pickles. Further indications of the diversity of our agriculture are found in the fact that Wisconsin is ninth in trout (sold 12 inches or larger), corn for grain, and cabbage for fresh market. Other agricultural products such as cherries, ginseng, Christmas trees, and pumpkins help define rural Wisconsin, along with an increasing number of award-winning craft cheeses being produced in the state.

The overall mission of the Agriculture Working Group is to generate science-based adaptation strategies for Wisconsin's diverse agricultural systems in anticipation of future changes in climate. Besides the farm community, this process will include Wisconsin scientists, policy-makers, interest groups and citizens. Adaptation strategies will have to be developed in a relatively short time, address a broad range of agricultural subject areas, and change as new information becomes available. These strategies will be produced through applied research and communication among all involved in this collaboration.

Because of the differential impacts of climate change across the state and the significant diversity of our agricultural system, it is highly unlikely that one or two core adaptation strategies can be developed for Wisconsin agriculture. Agriculture has been a critical dimension of Wisconsin from early settlement and the logging era through the period of industrialization, and it remains an important economic, social and cultural component of the state as we enter the Information Age.

As part of this first WICCI adaptive assessment report, we reviewed research that has already taken place regarding climate change and its impacts on Wisconsin row crop agriculture. Specifically, research has already investigated the impacts of historical and future climate change across the state on corn and soybean yields.

Impacts of Recent Climate Change on Wisconsin Corn and Soybean Yield Trends

Corn and soybean yield trends across Wisconsin have been favored by cooling and increased precipitation during the summer growing season. Trends in precipitation and temperature during the growing season from 1976 to 2006 explained 40 percent and 35 percent of county corn and soybean yield trends, respectively. Using county-level yield information combined with climate data, we determined that both corn and soybean yield trends were supported by cooler and wetter conditions during the summer because increases in precipitation appear to counteract negative impacts of recent warming on crop yield trends. Our results suggest that for each additional degree Celsius of future warming, corn and soybean yields could potentially decrease by 13 percent and 16 percent, respectively, whereas modest increases in precipitation (for example, 50 millimeters) during the summer could help boost yields by 5-10 percent, counteracting the negative effects of increased temperature. While northern U.S. corn belt regions such as Wisconsin may benefit from climate and management changes that lengthen the crop-growing period in spring and autumn, they are not immune to decreased productivity due to warming during meteorological summer.

Potential Impacts of Future Climate Changes and Increased Atmospheric CO_2 on Wisconsin Row Crop Agriculture

Based on historical relationships between county-level climate data and USDA crop yield information, across southwestern regions, corn yield variability has been most influenced (ranked by R^2 values) by July maximum temperatures and July precipitation, whereas across the northeast, daily high temperatures in September impacted corn yield variability the most. In contrast, soybeans were most affected by precipitation in July and August over the west central and southeast and by minimum daytime temperatures during May for northeastern counties close to Lake Michigan. Small increases in average high temperatures during

July and August (for example, 2-4º C), which are on the same order of magnitude that is projected under future warming scenarios with climate models, were correlated with annual yields that were 10-30 percent lower than the expected average values. Surprisingly, positive summertime precipitation anomalies of +50-100 percent translated into yield increases of only 3-11 percent. **Overall, crop yields were favored by cooler-than-average daytime high temperatures in late summer and above-normal temperatures in September.**

The IPCC (2007) reported that a mean local temperature increase of 1-2º C in the mid- to high-latitudes where agricultural adaptation took place could boost corn yields by 10-15 percent above the baseline. A 2-3º C increase in mid- to high latitudes coupled with adaptation could still allow crop yields to increase above baseline values, but a 3-5º C increase would mean yields would fall to the approximate baseline value and decrease by 5-20 percent without some type of adaptive strategy. Our composite results support these generalizations, as an increase of 2º C in the maximum monthly average temperatures in July and August translated into yield losses of 6 percent for corn and 2-4 percent for soybeans when year-to-year variability was taken into account. However, a warming magnitude of 4º C in monthly average maximum temperatures in July and August across Wisconsin could lead to corn and soybean yield losses of 22-28 percent and 13-24 percent, respectively, if adaptive measures do not occur. We note that the magnitude of this change differs depending on whether long-term trends in climate and yield are analyzed or the analysis uses a regression of year-to-year changes that compare yield anomalies to actual meteorological data each year. Nonetheless, **it appears that any degree of future warming during the core of the growing season would have a negative impact on productivity.**

New experimental data suggests that C_4 photosynthesis (corn) is already saturated at the current levels of atmospheric CO_2, and therefore any more increases in CO_2 will not be effective at boosting productivity in the future. One key study by Leakey et al. (2006) performed in Illinois revealed that elevated CO_2 (550 parts per million) did not stimulate an increase in photosynthesis or yield compared to current levels. In the case of soybeans, it appears that increases in yield could still occur as CO_2 increases in the atmosphere, but the projected increase is approximately 50 percent less than in the original studies that were performed using enclosures or chambers. It is suggested that across Wisconsin, soybean yields may be increased by approximately 13-15 percent as CO_2 levels climb towards 550 parts per million by 2050.

Adaptation Strategies

First, given the recent results from the WICCI Climate Working Group as well as this Agriculture Working Group report, we know that climate has been changing across Wisconsin for many decades and that future changes are likely to continue. Based on work published already (Kucharik and Serbin, 2008), we also know that recent trends in climate across Wisconsin have had a significant impact on agricultural production (that is, yield trends) of corn and soybeans across the state. In general, it seems that while warming temperatures in either of the shoulder seasons (spring, fall) would help boost agricultural production by extending the growing season across the state, increased warming during the core of the growing season (June through August) appears to have a negative impact on row crop production in our state. **The bottom line is that climate has changed and agriculture has already been impacted in an adverse way in some cases.**

Given the grand scale and diversity of agricultural systems in the state of Wisconsin and their connection to human decision-making and the economy, it will take many years to formulate adaptation strategies to deal with the potential negative consequences of climate change. However, the first step toward forming any adaptive strategy will be to convince managers and producers that climate change is real and that it is highly likely to continue. Furthermore, these same groups need to be confident that these changes in Wisconsin will significantly impact their decision-making, economic livelihood, and long-term prosperity (Howden et al., 2007). They will need to be assured that the necessary adaptations will be readily available to them, whether through new technology, new crops or hybrids, improved management practices (water resources), a diversification of their income stream, improved effectiveness of disease and weed management practices, or increased capacity for infrastructure to ameliorate heat-related stress on animals.

Therefore, the best adaptive strategy at the present time is to continue with a **strong research, education and outreach plan** that begins the process of integrating scientific results with stakeholders, farmers, business leaders, and other important agricultural groups.

Improving the collection of information across the state of Wisconsin would help us better understand how agricultural systems are responding to current weather and year-to-year variability as well as to longer-term changes in the climate system. This might be accomplished through the following types of activities:

- Develop a stronger presence of an agro-meteorology (or agro-climatology) program within the University of Wisconsin System, including courses that begin to train the next generation of environmental scholars to understand the connections between agriculture and climate.

- Support or seek support for placed-based research that integrates ecological and social science – possibly at the watershed scale (for example, the Yahara Watershed or the Central Sands Region) – whereby a combination of field work, numerical modeling, and remote sensing can be combined with the social sciences to better understand how ecosystem services associated with agricultural systems can be sustained into the future.

- Re-establish a network of meteorological stations across the state of Wisconsin that collect important observations, including estimates of evapotranspiration. For example, the state of Iowa has an extensive mesonet that feeds into the Department of Agronomy at Iowa State University, and data are available in real time through the Internet. This idea is not a new one in Wisconsin; Professor Bill Bland (soil science, UW-Madison) established a small network of stations in the 1980s and 1990s in different agricultural regions of the state

- Design and seek funding support for a program to collect on-farm information such as fertilizer/pesticide usage, other management practices, and yield responses, that would become a larger database available to researchers across the state. Unfortunately, we currently know very little about specific on-farm management and the response of our agricultural systems to weather and climate across the diverse geography of Wisconsin. This is particularly true of our specialty crops.

While these are not explicit examples of "adaptive strategies" for agriculture, they represent the first steps we must take to be in a better position to communicate what needs to be done to adapt to changing climate. We still need basic research and a new type of framework for integrating these new results into policy decision-making.

CENTRAL SANDS HYDROLOGY WORKING GROUP

Climate Change Influences on Wisconsin Central Sands Hydrology and Aquatic Ecosystems

Climate change could exacerbate already serious groundwater pumping impacts on Wisconsin Central Sands lakes, streams and wetlands. For example, if climate becomes drier or warmer, irrigation demands for groundwater may increase and further stress lakes, wetlands, and stream flows.
Getting out in front of climate change could begin now and might include doing a better job of monitoring aquatic systems and instituting groundwater pumping management schemes that explicitly consider aquatic resource health.

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The Central Sands

The Central Sands covers parts of five Wisconsin counties. The region is characterized by its thick (often greater than 30 meters) mantle of sandy glacial materials that cover impermeable bedrock. These sandy materials constitute a productive aquifer holding an important groundwater resource that feeds the area's more than 80 lakes (greater than five hectares), more than 1,000 kilometers of headwater streams, and extensive wetlands. These resources are highly prized not only for the ecosystems they support (coldwater fisheries, endangered and threatened species) but also for amenity values and recreational opportunities. The aquifer is also tapped by Wisconsin's highest concentration of high-capacity wells and greatest amount of groundwater pumping, used chiefly for supporting irrigated agriculture.

What makes the Central Sands region hydrologically interesting is that so much of its water cycle occurs underground. Groundwater is recharged by precipitation percolating through soils and is ultimately conveyed to surface waters. Lakes and wetlands exist where the water table intersects depressions in the landscape, and streams occur where groundwater discharges to channels. Thus, changes in the landscape's hydrologic budget that affect groundwater also affect aquatic resources and their ecosystems.

Although climate change might be expected to drive changes in the hydrology and aquatic resources of any landscape, the Central Sands region exemplifies a distinct case due to its prevalent irrigated land cover. Irrigated land has been increasing in extent in the Central Sands for about 50 years and currently covers about 175,000 acres in the area of interest. Irrigation utilizes groundwater to supply moisture to otherwise droughty soils, diverting baseflow from the region's streams and lowering water levels.

The potential effects of irrigation on aquatic resources have been explored in both classic studies in the 1960s and 1970s as well as in newer works. These suggest irrigation decreases net groundwater recharge by 20-25 percent compared with non-irrigated lands. This reduction has been sufficient to dry up some lakes and streams in the region under only moderately dry conditions.

Anticipated Climate Change

Wisconsin's climate has changed noticeably during the last half-century (Serbin and Kucharik, 2009) and is expected to continue to change. Already in the Central Sands, warmer conditions have been observed, manifested mainly as warmer nights (1.5 º C). The growing season has increased by 15-20 days. Precipitation has also increased, by an average of 50-150 millimeters per year^{-1} (about 10-15 percent). Future climate is expected to be warmer, with mean annual temperatures increasing by 2.6-3.6º C (4.7-6.5º F) by the mid-21st century, and 5.1º C (9.2º F) by late 21st century. Precipitation is expected to remain near current levels, but the time of year and amount of precipitation that arrives in extreme events may change. Wetter springs are likely, and drier summers are suggested but are less certain. Annual potential evaporation may increase by 10-20 centimeters across Wisconsin.

Vulnerability Assessment

We are in the early stages of assessing the vulnerability of groundwater resources in the Central Sands region. We have preliminarily qualitatively assessed how five primary climate drivers (annual precipitation, precipitation timing, temperature, humidity, frost during precipitation and snowmelt) and two secondary land drivers (irrigated land area, time under crop cover) may influence net groundwater recharge in the Central Sands. These are summarized in Table 1.

More precipitation, especially during non-summer months, would increase net groundwater recharge, causing more robust water levels and stream flows; the converse would cause the opposite. Warmer temperatures, especially during summers, would increase potential evapotranspiration (PET). (PET is the amount of evaporation that comes from soil and plants if water is not limiting.) Higher humidity decreases PET while lower humidity increases PET. Increased PET would only increase actual evapotranspiration (AET) on non-irrigated land when sufficient soil moisture is present, but increased PET would always result in increased AET on irrigated land during growing seasons, as irrigation makes up for any soil moisture deficit. We speculate that the timing of frost in the soil may be a consideration if frost limits percolation during what would otherwise be recharge periods.
We anticipate that warmer temperatures will result in longer growing seasons, with an adoption of longer-season crops and perhaps more double crops. Both would drive increased irrigation demand. Similarly, we anticipate that the trend toward more irrigated fields will increase, perhaps spurred by both the challenges (timing of moisture with respect to crop need) and opportunities (longer growing seasons) brought about by climate change.

Adaptation Strategies

Adaptation strategy ideas are in very initial stages. The working group suggests two initial adaptation strategies: First, prepare for adaptive management. This can begin now by improving systems for monitoring water levels and stream flows. Second, develop groundwater management capacity. Currently, there is no framework for managing groundwater withdrawals consistent with societal goals for surface water health.

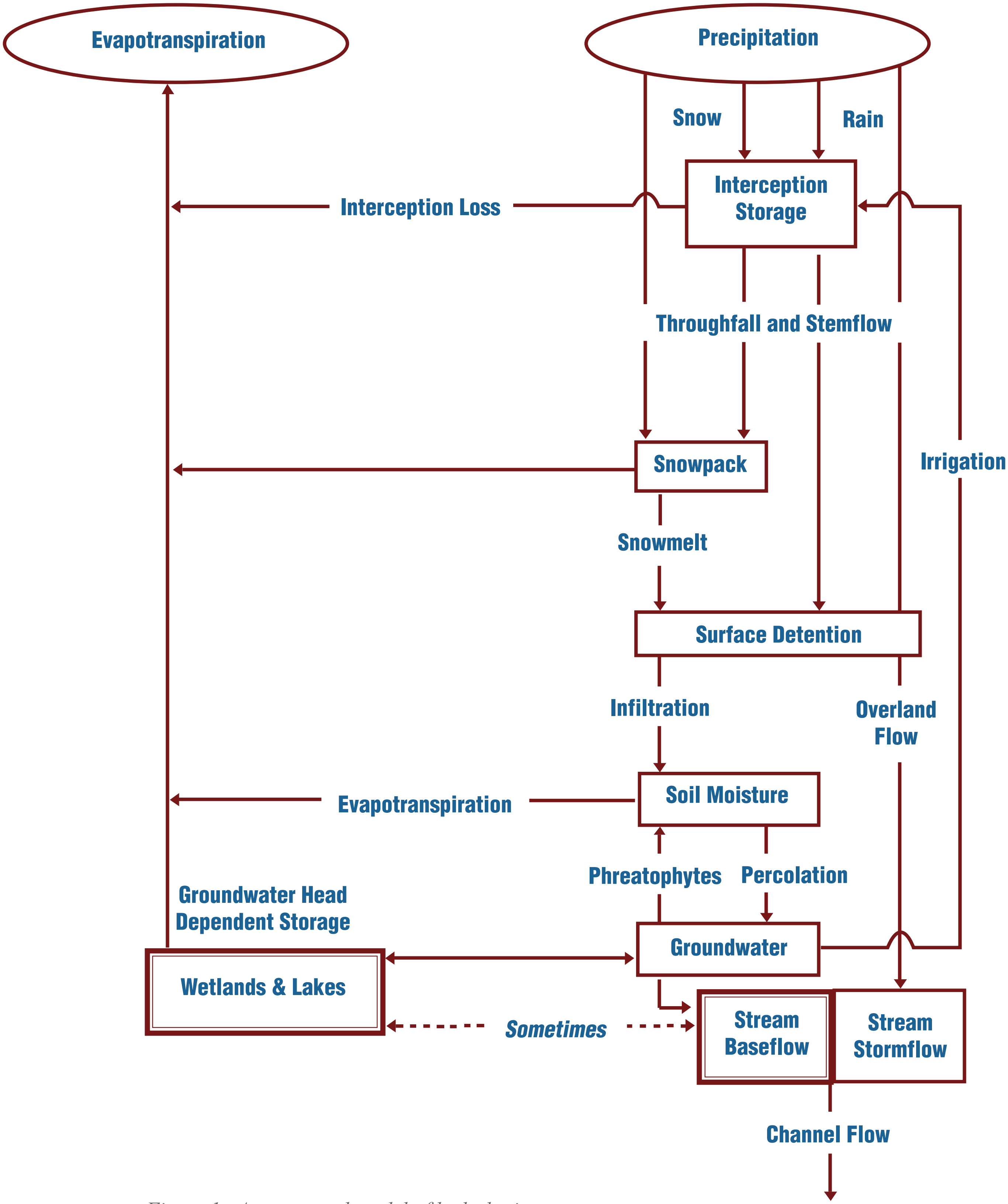

Figure 1. A conceptual model of hydrologic processes.

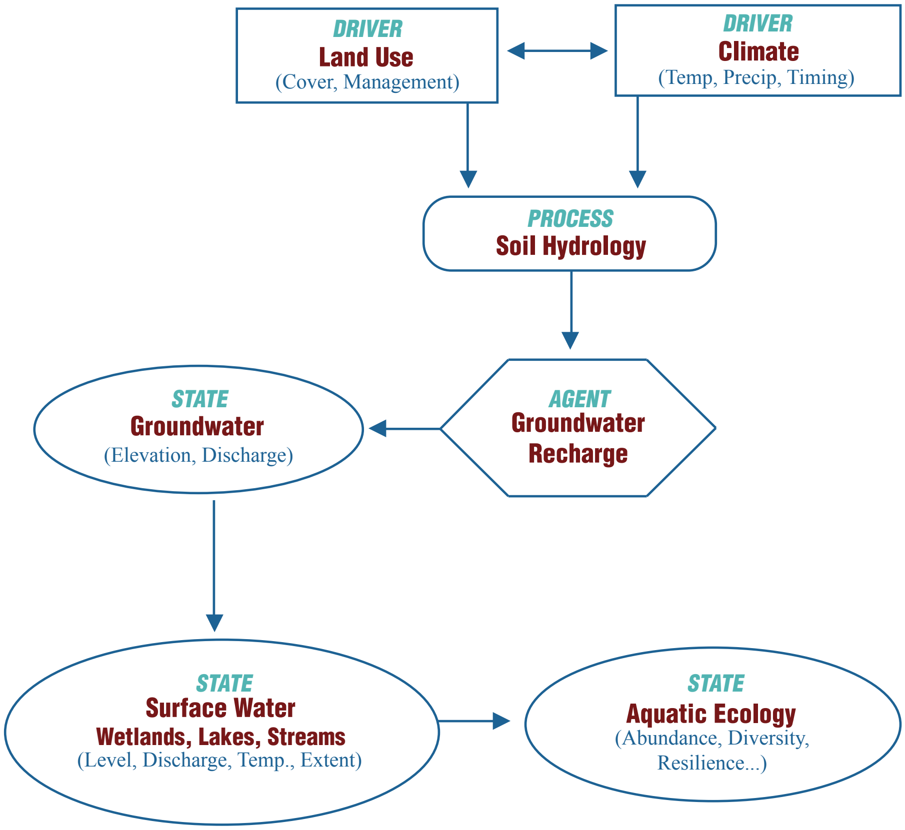

Figure 2. A conceptual model of evolving land cover and management.

CLIMATIC OR HYDROLOGIC DRIVER	RECHARGE DIRECTION	RATIONALE / COMMENT
PRIMARY		
Precip, annual total		
More	+	Increased water into system
Less	-	Decreased water into system
Precip, timing		
More Fall, Winter, Spring	+	PET is lower this time of year
More Summer	-	PET is greater this time of year
Temperature		
Warmer	-	PET increases
Humidity		
More	+	PET decreases
Less	-	PET increases
FROST DURING THAW/ PRECIP PERIODS		
More	-	Frost encourages runoff
Less	+	Lack of frost encourages recharge
SECONDARY AND CULTURAL DRIVERS		
Crop cover, longer or double crops		
More	-	Greater LAI for more of the year
Irrigated land		
More	-	Greater AET for more of the year

Table 1. Potential effects of climate change on groundwater recharge.

COASTAL COMMUNITIES WORKING GROUP

CLIMATE CHANGE AND WISCONSIN'S COASTAL COMMUNITIES

Nearly all of Wisconsin's communities will need to adapt to the state's changing climate over the next few decades and beyond. Most of the state's cities, villages and towns will need to adapt to changes in the frequency and intensity of rainfall events and ensuing runoff. Wisconsin's coastal communities likewise will need to adapt to increased storm runoff but also will need to prepare for changes in lake levels and wave and erosion impacts on their shorelines and harbor structures.

Although we cannot say with any certainty whether lake levels will rise or fall, the general consensus is that warmer temperatures along with reduced snowpack and shorter duration of ice cover will result in greater evaporation during the relatively dry winter months and overall lower lake levels. Low water levels will allow beaches and beach ridges to build, and the vegetation edge that anchors them will move toward the lake. In Wisconsin, the ordinary high water mark (OHWM) is determined by vegetation, not elevation; as such, the OHWM can move, based on prolonged water level changes. If construction follows the OHWM lakeward, the new structures can be exposed to risk of loss or damage when severe storms strike or water levels rise.

Increased storm intensity and frequency could increase shore and bank erosion and damage existing lakefront property due to erosion from storm runoff and flooding. Changes in freeze-thaw cycles may adversely affect coastal bluff stability and accelerate slope erosion processes. Prolonged dry conditions can eventually lead to major slope failures during heavy rainfall events. Deep-rooted vegetation may help anchor coastal slopes, but changes in vegetation in response to climate changes may alter coastal vegetation forms.

Marinas and harbors are subject to climate change as well. Lower lake levels can increase the need for dredging to allow loading of freighters and avoid bottoming out of recreational vessels. Low water levels may adversely affect boat launches at marinas and public access points. Greater wave heights will be associated with higher water levels and could result in damage to harbor structures and port infrastructure and to vessels in harbors and marinas.

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Climate change may significantly affect tourism on Wisconsin's Great Lakes by impacting beach health. Increased water temperatures and runoff from intense storms may create an environment that deposits and supports pathogens on beaches. More pathogens on beaches will most likely lead to more frequent beach closures. Higher lake levels may extend the reach of pathogens. Although the impact on Wisconsin has not been measured, beach closures do have economic implications.

Higher lake levels may reduce the area of beaches, limiting recreational activities on the shoreline. Lower lake levels may change the ecology of a beach and offshore habitat, which, in turn, may affect the aesthetics of the lakefront. Changing lake levels may affect boating access to piers and marinas. Changes in lake levels may impair fish spawning habitat, reducing or eliminated recruitment of young fish and affecting Great Lakes sport and charter fisheries, which could affect tourism. Aesthetic changes in receding shorelines or degraded ecosystems may make beaches and hotels less appealing to tourists.

Resources are currently in development nationally and in the Great Lakes region to assist coastal communities with planning to adapt to a changing climate. At the national level, the National Oceanic and Atmospheric Administration's Office of Ocean and Coastal Resource Management is preparing a report titled *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. A draft includes chapters on climate change and the coast, planning process, vulnerability assessment, adaptation strategy, and plan implementation and maintenance. Adaptation measures addressed in the report include:

- Growth and development management (zoning, redevelopment restrictions, conservation easements, and compact community design).

- Property protection (acquisition, relocation, setbacks, building codes, retrofitting, infrastructure protection, and shore protection structures).

- Shoreline management (regulation and removal of shore protection structures, rolling easements, living shorelines, beach nourishment, dune management, and sediment management).

- Coastal and marine ecosystem management (ecological buffer zones; open space preservation and conservation; ecosystem protection and maintenance; ecosystem restoration, creation, and enhancement; and aquatic invasive species management).

- Water resource management and protection (stormwater management, green infrastructure, and water supply management).

Wisconsin's coastal communities will need to consider all or many of these issues as they develop action plans that accommodate climate change in their community growth. This report provides an assessment of current conditions and potential changes along the Great Lakes coasts and provides details on many of the issues community managers will need to consider in developing those plans. Finally, we outline both specific and general means of adaptation that community planners should consider as they devise means to move their communities into a future that includes climate variability and change.

The next steps in assessing climate adaptation in Wisconsin's coastal communities are (1) to acquire and review adopted comprehensive and hazard mitigation plans to assess whether and how climate change issues are addressed, (2) to determine if any coastal communities have adopted climate action plans and assess their quality, and (3) to survey planners in coastal communities to determine ongoing climate adaptation activities and assess if any technical assistance is desired.

COLDWATER FISH AND FISHERIES WORKING GROUP

Wisconsin is recognized for its abundance of coldwater streams, which include more than 10,000 miles of classified trout streams that provide fisheries for brook trout and brown trout. Expected climatic changes in air temperature and precipitation patterns across the state may threaten the viability of Wisconsin's inland trout resources. In this analysis, we use computer models to show how the distribution of some coldwater fishes may change in response to climate warming, and we discuss adaptation strategies that can be employed to lessen the impacts of climate change on coldwater fishes in Wisconsin.

Wisconsin has rich and varied coldwater resources including streams, spring ponds, and thermally stratified lakes. In addition to more than 10,000 miles of managed trout streams, another 22,000 of Wisconsin's 54,000 stream miles may be suitable for coldwater species such as mottled sculpin. Wisconsin also has about 1,000 spring ponds that support coldwater fishes such as brook trout and nearly 3,000 stratified lakes, of which about 170 contain self-sustaining populations of coldwater fishes such as cisco. Lake trout are indigenous to Wisconsin and are also present in some inland lakes.

Climatic changes in air temperature and precipitation will affect water temperature and flow in streams. Climate change will also affect water temperature and groundwater input to spring ponds. Many lakes in Wisconsin thermally stratify during summer, with the coldest layer occurring at the bottom. The suitability of this cold layer of water for coldwater fishes will be affected by climate change impacts on the duration of stratification and the consequent depletion of dissolved oxygen in this layer. An increase in the duration of lake stratification during the open water period will worsen the depletion of dissolved oxygen in the coldwater layer to levels stressful or lethal to coldwater fishes, resulting in the decline of their populations.

Coldwater fishes native to Wisconsin are an integral part of our state's natural legacy, and coldwater fisheries are a core part of our culture and identity. The restoration of native fisheries in Wisconsin waters is a stated goal of the state agencies entrusted to man-

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age these resources. Anglers pursuing trout and other coldwater fishes also make a significant contribution to our local and state economies. In the face of changing climate conditions it is important to assess the potential impacts on coldwater fish and fisheries and to implement adaptive management strategies to ameliorate climate change impacts on Wisconsin's coldwater streams and inland lakes and their fisheries.

We used watershed-scale models to predict the changes in coldwater habitat and distributions of coldwater fishes that might occur under three different climate change scenarios. For streams, we considered three coldwater species: brown trout, brook trout, and mottled sculpin (Figure 1a-c). For stratified lakes, we considered one species: cisco (Figure 1d). We did not have enough information to model spring ponds.

Figure 1. a. Brown trout Salmo trutta. b. Brook trout Salvelinus fontinalis. c. Mottled sculpin Cottus bairdii. d. Cisco Coregonus artedi.

For the coldwater streams and stratified lakes, we ran models for each stream reach or stratified lake in the state under current climate conditions and three climate warming scenarios projected for Wisconsin by the Climate Working Group: (1) a "best case" scenario, in which summer air temperature increased by slightly more than 1.8° F and water temperature by 1.4° F; (2) a "moderate case" scenario, in which air temperature increased by 5.4° F and water temperature by 4.3° F; and (3) a "worst case" scenario, in which air temperature increased by 9° F and water temperature by 7.2° F. For these models we assumed water temperature responds the same to air temperature in all streams, there was no change in precipitation across the climate change scenarios, and there was no change in land use over time from current conditions. These assumptions will be relaxed in future model development. Improvements in the stream models are in progress and include capabilities to incorporate variation in precipitation and groundwater inputs across the state for use in predicting streamwater temperatures. The stratified lakes model did not appear to be strongly sensitive to lake productivity even though lake productivity is expected to affect dissolved oxygen in the bottom cold layer of water and, hence, lake suitability for cisco.

Climate change will likely cause reductions in all coldwater habitats and fish species in Wisconsin. Increases in air temperature will negatively affect thermal conditions required for the persistence of coldwater fishes. Changes in the amount and distribution of precipitation across the state may ameliorate or exacerbate the reductions in coldwater habitat and fishes. The magnitude of the reductions in coldwater fishes will therefore depend on the type and location of the habitat, the particular fish species that live there, and the nature and severity of the climate change that occurs.

Under current conditions, our models show mottled sculpin to be the most widespread coldwater fish species in Wisconsin streams, with brook trout the least widespread and brown trout intermediate. All three species declined in distribution under all three climate change scenarios. Brown trout declined least and brook trout most. Under the worst-case climate change scenario, brook trout were predicted to be extirpated from Wisconsin streams, with mottled sculpin reduced in distribution by 95 percent and brown trout by 88 percent.

Losses of habitat were expected to occur evenly across the state and were not noticeably concentrated in any particular geographic region. The models for stratified lakes indicated that climate change could also cause major declines in cisco populations.

Climate-induced changes in stream temperature and flow will not be uniform. Interactions between air temperature and precipitation and stream temperature and flow are mediated by stream channel, riparian, and watershed characteristics. It follows that the ability of streams to buffer change in water temperature and flow against change in climate will vary. Herein lies opportunity for managing climate impacts on inland trout and other coldwater resources. We suggest two types of adaptation strategies that can be used to lessen the impact of climate warming effects on trout. The first involves environmental management activities to offset the impacts of rising air temperatures and changes in precipitation. These activities include land, riparian, and water management and stream restoration. The second involves a triage approach to identifying potential impacts of climate change on coldwater resources and allocating management resources to those coldwater habitats most likely to realize success. Some streams, for example, may face inevitable losses of coldwater fishes, some may be resilient to climate impacts, and some may allow for persistence of coldwater fishes contingent on management approaches used to counteract climate impacts. Appropriate management actions may include environmental adaptation strategies as well as changes in angling regulations and fish stocking strategies. We expect that a proactive application of these adaptation strategies will help protect Wisconsin's coldwater fishes and fisheries from the impacts of our changing climate.

FORESTRY WORKING GROUP

Over the next 100 years, Wisconsin's climate is expected to undergo significant changes that may include rising average temperatures, longer growing seasons, shorter winters, and more severe storm events, floods, and droughts. Significant impacts on forest communities across the state are expected.

Climate change will probably impact all forest communities, but certain forest ecosystems may be more sensitive to change than others. With diverse forest types within the state it is important to identify types of forests and trees which are potentially most sensitive to climate change and to develop strategies to assess and manage changes within the forest matrix.

Climate change impacts on forests are important to the state of Wisconsin. Forty-six percent of Wisconsin's 35 million acres are forested. Wisconsin's forest resources can be divided into two broad categories, the northern mixed forest and the southern broadleaf forest. These two forest types exist in Wisconsin because they have adapted to different climatic conditions. This differentiation between northern and southern forests follows the Tension Zone, a zone of vegetative change that generally follows a gradient in temperature and moisture across the state from northwest to southeast. Wisconsin's forests occur on a variety of soils and landscapes, which will be impacted differently by climate change. This report uses a system of landscape

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classification called ecological landscapes to further divide southern Wisconsin into areas such as the western coulees and ridges, Central Sands and Lake Michigan coast so that potential local climate impacts can be better examined.

Wisconsin's forests can adapt naturally to climate fluctuations; climates have changed in the past, and types, severity, and rates of change have been variable (for example, forests responded and re-established themselves after glaciation). However, the expected rate and severity (magnitude) of climate change will probably be greater than in the past. These potential changes need to be examined in order to estimate the magnitude of changes and how the forests may adapt. However, the types, severity, rates, and pattern of climate changes over the next 50 to 100 years and beyond are extremely difficult to forecast, and the actual response of forests to climate change is highly uncertain. The Forestry Working Group (FWG) is investigating these potential impacts by working closely with climate scientists, biologists, foresters, and stakeholders to better understand Wisconsin's changing climate and its potential effects on native and urban forests. The FWG used models that attempt to simulate future forest site suitability, the WICCI downscaled climate data, climate analogs and regional expert panels to estimate the impacts of potential late summer drought, decreased snow cover, reduced soil moisture, winter rain, invasive species, insect pests and diseases in the context of forests. Each of these scenarios is hypothetical and would potentially occur at a given period of time, some scenarios are more likely than others, and actual climate and forest ecosystem responses 50-100 years in the future are unknown. The results of these investigations led the working group to recommend actions that would monitor changes in forests, increase the probabilities of impacts assessment, improve adaptive management, and maintain and increase diversity and connectivity across spatial scales.

In order to assess the potential impacts to forests, natural resource professionals worked with climate scientists to project hypothetical forest impacts based on new climate and forest models that cover the state. Forest site suitability models (also referred to as climate envelope models) are available from the USDA Forest Service, Canadian Forest Service and University of Wisconsin and were used in the vulnerability assessment. These models show where the ideal conditions to grow Wisconsin tree species might change as climate changes 100 years into the future. This information was combined with climate analog models that show where climates in the United States exist now that might be similar to what Wisconsin would experience 50 and 100 years into the future. Furthermore, the working group had the benefit of cooperation with the USDA Forest Service vulnerability assessment drafted for northern Wisconsin forests to provide a parallel integration of similar forest models and expert assessments. Finally, the WICCI FWG solicited the expertise of foresters, planners and biologists throughout the state to gain local perspectives on how the projections of both climate and forest models may affect the significant forest features for which they provide stewardship across the state.

For the first iteration of the forest vulnerability assessment, the FWG adopted a scale and scope that was consistent with existing resources and information. The group examined forest vulnerability at the scale of northern and southern sections of the state separated by the Tension Zone. The south was further divided into ecological landscapes. The north will be examined at ecological landscape scale in the second assessment. The vulnerability assessment covers points in time centering around 2050 and 2100 for impacts. These time frames are consistent with information that is readily available from climate and forest models; further subdivisions of time would have required additional model runs. The scope of the assessment covered climate change vulnerabilities and adaptation consistent with definitions used by other WICCI groups. These vulnerabilities were confined to ecosystem attributes such as forest establishment, pest interactions, disease interactions, species migration, biodiversity, soils, species moisture and temperature tolerances. Impacts on forest-based economies, communities and recreation were outside the scope of this assessment but are planned for the second assessment.

Key Findings

- **Young forests may be vulnerable:** Young forest saplings and seedlings could be at risk of stress and mortality from changing temperature and precipitation patterns. Mature trees have large root systems and sugar reserves that allow them to endure shorter droughts and moderate pest and disease attacks, while small seedlings will often die off under a short drought or heavy competition from other plants. This trend could lead to more forest sites being difficult to regenerate through natural seeding and sprouting.

- **Forests are vulnerable to changes in soil moisture**: Soil moisture has a strong link to the types of forest species that grow on a particular site, and changes in precipitation, hydrology and rate of evaporation will impact the types of forest species in a forest. However, it is unknown what changes in moisture availability will occur across the state.

- **Central hardwoods may increase**: Central hardwood species such as hickory, black oak and black walnut might expand their range in Wisconsin under a warmer climate. However, it is uncertain how this forest type will be affected by much wetter or much drier conditions

- **Boreal species are at risk**: Warmer winter temperatures and possible late summer droughts would increase stress in species that are currently at the southern edge of their natural range limits, such as aspen, white birch, white spruce, black spruce, balsam fir, jack pine and red pine. Species under increased stress will be more susceptible to damage from insects and diseases.

- **Jack pine could be resilient**: Jack pine barrens and forests are adapted primarily to extremely dry sandy sites and are not so dependent on climate. If these dry sandy sites persist, jack pine may prove more resilient than other boreal species. However, because it is a boreal species at the southern edge of its range, there are concerns about jack pine, and it could be replaced by scrubby oaks on dry sites.

- **Conifer lowlands are vulnerable**: Black spruce and tamarack lowland forests are sensitive to changes in water tables and snow cover. Less snow or shorter durations of snow cover could lead to freezing damage in fine root systems. In addition, changes in the water table could flood or dry out the moist wetland surface needed to establish seedlings on these sites.

- **Invasive species will become more aggressive:** Many of the invasive species in Wisconsin are habitat generalists and will probably be well adapted to grow in warmer temperatures and a carbon-dioxide-enriched atmosphere. Furthermore, their ability to rapidly colonize disturbed sites will afford these plants an advantage in areas where such things as floods, droughts and tree mortality open up growing space. New invasive species may colonize sites in Wisconsin.

- **Insects and pathogens:** Pests and pathogens are likely to experience changes in population cycles and competitive relationships. Some could become greater problems than they are now.

- **Urban forests can respond well**: The forests that grow in the streets and parks of Wisconsin's towns and cities can respond well to climate change impacts. Cities can replant urban trees with species that are more suited to warmer temperatures, and expanding these forests will help to shade and cool the urban heat island effects that are projected to increase. However, resources to implement this response remain limited in municipalities across the state.

Key Adaptation Strategies

- **Monitor vegetation for impacts caused by climate change:** Forest ecosystems are complex communities, and monitoring sites will provide a means to track the pace and extent of change, tree species responses and associated changes in forest shrubs, wildlife and herbs.

- **Increase model certainty of long-term climate forecasts:** If opportunities arise to improve confidence in long-term future climate trend prediction, particularly precipitation, supporting these endeavors could provide better inputs into future forest-condition modeling; however, long-term climate prediction will probably continue to have a high degree of uncertainty.

- **Adaptive management:** Forest managers already use a number of tools, policies and practices to ensure that the forests of Wisconsin are sustained into the future. An assessment of the usefulness of these forest management tools and policies, such as invasive species management and assisted regeneration, can be valuable in reducing climate change impacts through resource investment rather than re-invention. Adaptive responses that identify, slow and constructively manage change will be important tools in helping forest managers cope with changing forest conditions.

- **Manage for diversity across scales**, particularly species diversity.

- **Create and maintain landscape connectivity**.

Notes on Working Group Membership

The membership of he WICCI Forestry Working group varies by participating function. Group members fluctuate depending on the task to be addressed and are outlined in this section.

Sponsorship: The initial formation of the Forestry Working Group occurred in August 2008 with group sponsorship by Darrell Zastrow of the Department of Natural Resources (DNR) and WICCI Science Council, and Dr. Raymond Guries of the University of Wisconsin. Avery Dorland of the DNR is the current chair of the working group, acting as a Liaison to the WICCI Science Council.

Researchers: With the support of the Forestry Working Group, Dr. Jack Williams and Dr. Sam Veloz were able to develop climate analogs for the ecological landscapes of Wisconsin. Dr. Adena Rissman, Dr. Eunice Padley and Dr. Chadwick Rittenhouse are investigating the links between land use changes and adaptation.

Editors: The Vulnerability Assessment was compiled using information from published research, expert opinion collected at the Southern Forests Workshop and the USFS Climate Change Response Framework's Vulnerability Assessment. This information was synthesized and edited by Dr. Jack Williams of the University of Wisconsin; Dr. Eunice Padley, Carmen Wagner, Sarah Herrick and Avery Dorland of the DNR.

USFS CNNF Climate Change Response Framework: The Vulnerability Assessment within the Chequamegon Nicolet National Forest's Climate Change Response Framework was created in partnership with Dr. David Mladenoff of the University of Wisconsin; Dr. Louis Iverson, Linda Parker and Matthew St. Pierre of the United States Forest Service and Dr. Chris Swanston, Maria Janowiak, Dr. Leslie Brandt and Patricia Butler of the Northern Institute of Applied Carbon Science.

Reviewers: Eunice Padley, Carmen Wagner, Joe Kovach

Southern Forests Workshop: The panel of natural resource professionals assembled to evaluate the climate impacts on the forest components of the ecological landscapes in southern Wisconsin were: Owen Boyle, Bill Carlson, Jane Cummings Carlson, Avery Dorland, Sarah Herrick, Brad Hutnik, Karl Martin, Mike Mossman, John Nielsen, Ryan O'Connor, Dr. Eunice Padley, Julie Peltier, Jeff Roe and Carmen Wagner of the DNR; Dr. Sarah Gagne, Dr. Adena Rissman, Dr. Chadwick Rittenhouse, Dr. Janet Silbernagel, Dr. Sam Veloz and Dr. Jack Williams of the University of Wisconsin-Madison; Linda Parker of the United States Forest Service and Dr. Les Werner of the University of Wisconsin-Stevens Point.

GREEN BAY WORKING GROUP

Assessment Report of Climate Change Impacts on the Green Bay Ecosystem

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Over the next 100 years, climate change will have significant impacts in the Great Lakes region of North America; particularly affected will be the shallow bays identified as freshwater estuaries, which are more sensitive to increases in temperature, precipitation and runoff than other regions of the Great Lakes. One such estuary, Lake Michigan's Green Bay, located in northeastern Wisconsin, is one of the largest freshwater estuaries in the world. Long-term predictions for the Great Lakes include both warmer and wetter conditions, with mean summer temperatures in Wisconsin increasing by 4.7°-6.5° F by the middle of the 21st century and an increase in precipitation during winter and spring months. In addition to warmer and wetter conditions, scientists expect an increase in the frequency of heavy rainfall events. By mid-century the probability of an April rainfall event larger than one inch in Green Bay is predicted to be 0.523. This is 12 percent higher than at present. By the end of the century, the probability of exceeding the one-inch threshold is 0.613.

Green Bay is characterized as an estuary because it functions as a nutrient trap with very high biological productivity and because of the thermal and chemical differences between the water of the tributaries and that of Lake Michigan. The mixing processes in Green Bay are complex and driven by a wind-induced seiche, a small lunar tide, and temperature differences in water masses. Warm water enters the bay in the south, and at depth, cooler water enters from the north through several channels from Lake Michigan. This layered system operates somewhat like a conveyor belt, with warmer nutrient-laden surface water moving north on the east coast and cooler Lake Michigan water moving south at depth on the west coast.

The head of Green Bay originates at the mouth of the Fox River, the largest tributary of Lake Michigan. While representing only 7 percent of the surface area and 1.4 percent of the volume of Lake Michigan, the bay receives approximately one third of the total phosphorus loading within the Lake Michigan basin. The biogeochemical cycles in Green Bay are dominated by the nutrient inputs from the Fox-Wolf River watershed with an area of 6,400 square miles, equivalent to one third of the Lake Michigan basin. Approximately 70 percent of the phosphorus and suspended sediment load to the southern bay enters from the Fox River, including an estimated 330,000 tons of sediment annually and 1,210 tons of total phosphorus.

The large catchment and the shallow basin would result in nutrient-rich waters even without human influence. However, Green Bay and the Lower Fox River have been severely polluted since as early as 1925. Even so, the existing abundance of the bay's habitats remains vital to commercial and sports fishermen, boaters, duck hunters, beachcombers, bird watchers and many people in the region who depend on it, both culturally and economically.

Stakeholders, both public and private, have spent hundreds of millions of dollars in efforts to reduce pollution and restore habitat in the Green Bay ecosystem. Over the last 40 years or more, they have made progress in restoring the ecological integrity of the bay and the many uses it provides. Scientists and managers have recognized that the Fox River and the Green Bay ecosystem have become degraded because they are impacted by multiple stressors, not just one or two causal agents. Climate change poses a new kind of threat to the bay and its resources because it may alter the impact of existing stresses on the system. Consequently, as part of the Wisconsin Initiative on Climate Change Impacts (www.wicci.wisc.edu) a Green Bay Ecosystem Working Group formed; its mission is to develop a collaborative approach, utilizing applied research, modeling, and adaptive guidelines to generate management strategies that address future climate change impacts. Adaptive management approaches will be developed and shared with Wisconsin policymakers, stakeholders and citizens. The essential step in developing adaptive strategies to address climate change impacts is to assess the potential risks to the resource or system of interest.

One of the primary objectives of all WICCI working groups is to assess the vulnerabilities of the particular resource or ecosystem to the potential impacts of climate change. The Green Bay Ecosystem Working Group has focused initially on valued components of the natural ecosystem and climate-caused changes that will likely occur over the next 30 to 50 years. It is our intent to consider the built environment at a later time. In any case, the ultimate goal is to formulate adaptive management guidelines for the Green Bay ecosystem resources and the Green Bay community.

Assessing Risk and Vulnerabilities

Based on previous experience, the Green Bay Working Group assessed the potential consequences of climate change by evaluating the **risk** posed to the Green Bay Ecosystem from regional shifts in temperature, precipitation and storm events. The relative magnitude of risk to valued components of the ecosystem can be estimated by examining the interactions among ecosystem stressors and the valued components of ecosystems using the mathematical tool of fuzzy set theory. Briefly, fuzzy set theory is an area of mathematics that provides a theoretical basis for making informed judgments and decisions when full precision is lacking. Fuzzy set theory enables one to draw logically valid conclusions based on sets whose memberships are specified in a tertiary manner or some other non-binary form. When used in conjunction with expert insight, group knowledge can be synthesized and priorities identified.

The Green Bay Working Group has conducted two separate workshops to assess how climate change may impact the Green Bay ecosystem. The first workshop, held in June 2008, assessed the way in which climate change is likely to alter ecosystem stressors. The second workshop, held in August 2009, assessed the potential impact of climate change on a select group of conservation targets of particular interest to The Nature Conservancy. Both workshops combined involved 30 scientists and resource managers with expert knowledge of the Green Bay ecosystem. The purpose of the workshops was to delineate the risk and vulnerabilities of the system to climate change impacts and thereby better inform development of adaptive management strategies. Both reports are available on the WICCI Web site (www.wicci.wisc.edu) under the Green Bay Working Group.

An assessment of climate change impacts on the conservation targets for Green Bay reveals that the most vulnerable targets, in descending order, are northern pike, coastal wetland community, littoral zone community, and lake sturgeon. These are followed by benthic community, migratory diving ducks and colony nesting birds. The vulnerabilities reflect an increased risk to the targets due to the exacerbating impact of climate change on the existing threats. The threats, in descending order of importance, are agricultural runoff, invasive species (carp), urban runoff and residential development. These four are followed by dams, the invasive species *Phragmites*, industrial waste and zebra mussels. The increased risk to a particular target derives from either the combined effects of the climate change components or from an individual climate change component. The six climate change components used in the analysis are:

- Increasing air and water temperatures
- Seasonality (shorter winters, earlier springs)
- Precipitation (higher in winter and spring)
- Periodicity of storm events (more frequent)
- Lower record and average water levels
- Shifting wind fields during summer from the southeast

In addition to considering vulnerabilities of and threats to conservation targets when contemplating adaptive management strategies, we also considered how climate change may alter the existing stressors on the Green Bay ecosystem. The analysis from our first workshop reveals that the most significant stressors to the Green Bay ecosystem under climate change conditions are nutrient loading, solids loading, aquatic exotics and wetland/shoreline filling. These top-ranked stressors are followed by pathogens, biological oxygen demand, hydrologic modifications and persistent organics.

When we compare the most significant ecosystem stressors from the first workshop to the most important threats from the second workshop, runoff and related phenomena appear in common. Consequently, it was imperative that runoff and related phenomena (that is, nutrient loading, solids loading, residential development, pathogens, biochemical oxygen demand, and hydrologic modifications) be given high priority when developing adaptive management strategies for conservation targets in Green Bay.

Expert opinion is consistent regarding runoff as the most significant impact associated with climate change. Consequently, further effort to quantify the magnitude of runoff under climate change conditions is warranted. Evidence to date reveals that nutrient and suspended solids loading to tributaries and the bay is event-driven. A significant change in future climate will likely affect amount and timing of phosphorus (P) and total suspended solids (TSS) flux to Green Bay. Scientists from the University of Wisconsin-Milwaukee and the University of Wisconsin-Green Bay are collaborating with WICCI in a project funded by the National Oceanic and Atmospheric Administration to use downscaled climate data generated by the Climate Working Group in a computer runoff model (the Soil and Water Assessment Tool) to predict the impacts of climate change on P and TSS inputs to lower Green Bay. The overall goal is to evaluate and develop methods to address the effect of climate change on phosphorus runoff and TSS inputs to lower Green Bay as well as changes in runoff.

Objectives are:

- To quantify the amounts of P and TSS that are discharged to lower Green Bay from the lower Fox River sub-basin under several future climate scenarios and to compare the amounts to historical conditions.
- To evaluate changes in the effectiveness of P and TSS runoff control practices to determine if their relative efficacy is altered under future climate conditions.

This study is part of an ongoing effort by the Wisconsin Department of Natural Resources to develop a Total Maximum Daily Load (TMDL) for P and TSS for the Fox River and Green Bay. We will delay development of specific adaptive management strategies for P and TSS runoff until the related TMDL has been approved and the climate-related Soil and Water Assessment Tool modeling is completed. However, it is still possible and desirable to move ahead and develop adaptive management strategies for other threats (for example, invasive species, residential development, dams and industrial waste), as they may impact the eight conservation targets. Runoff may also be considered in a general sense.

Adaptive Management Strategies

The Green Bay Working Group held its initial adaptive management workshop on April 7, 2010. A mix of 20 professionals from academia, the Wisconsin Department of Natural Resources, the U.S. Fish and Wildlife Service, and The Nature Conservancy convened for a day at the University of Wisconsin-Green Bay campus to identify potential adaptive management strategies for Green Bay conservation targets. Participants prepared for the workshop by reviewing previous results of the earlier risk assessment workshops and reading a published review of climate adaptation literature. Individuals were assigned to one of the five breakout groups to address the five most vulnerable conservation targets: northern pike, coastal wetland community, littoral zone community, lake sturgeon, and benthic community. The groups were prompted to keep in mind the five overarching principles of adaptive management identified in the literature review article, "New Era for Conservation," published by the National Wildlife Federation. These principles are:

- Reduce other non-climate stressors.
- Manage for ecological function and protection of biodiversity.
- Establish habitat buffer zones and wildlife corridors.
- Implement proactive management and restoration strategies.
- Increase monitoring and facilities management under uncertainty.

Another way of envisioning adaptive strategies is from a conservation strategy perspective, such as:

- Protection
- Land/water management
- Species management
- Education/awareness
- Laws and policies
- Economic incentives

Other general strategy categories include research, using existing laws or policies (mainstreaming), enhancing resilience and adaptive capacity and externality control.

The adaptive management strategies developed by the separate breakout groups are outlined below:

Northern Pike

- Review Chapter 30 WI Stat. (waterways and wetlands) and Chapter 31 (dams) for adequacy in protecting coastal wetlands and removing or modifying dams.
- Continue closed season and daily bag limits for northern pike on tributary streams.
- Examine zoning regulations for adequacy in protecting hydrologic integrity of both surface and groundwater of west shore coastal zone.
- Support TMDL for phosphorus and total suspended solids.
- Bank sloping channel restoration.
- Dam removal management.
- Manage water levels at restoration sites.
- Continue emphasis on wetland acquisition and stream habitat and wetland restoration.
- Manage age structure to create resilience in face of interdecadal water level variability.
- Determine minimum number of age classes needed for resilience (see above).
- Assess effects of the loss of submergent aquatic vegetation on predation and juvenile mortality.
- Define relations between nutrient loading water quality and sustainable spawning.

Wetlands

- Examine policies and regulations protecting lands below the ordinary high water mark. Policies need to be preemptive to protect.
- Inventory fragmentation and connectedness and identify critical habitat for protection.
- Protect and restore integrity of hydrologic regime.
- Consider seed bank manipulation to counter *Phragmites* invasions of exposed lakebed.
- Control polluted runoff through TMDL and best management practices, particularly stream bank buffers.
- Consider woody vegetation for stream buffers.
- Assess effectives of conventional best management practices and support development of new methods.
- Assemble oral histories, photos, records, and studies to document previous conditions; present to the public.

Littoral Zone Community

- Use and support the ongoing TMDL effort.
- Incorporate climate change scenarios in next modeling effort and engage community planning.
- Examine adequacy of treatment systems and stormwater infrastructure to accommodate climate change conditions.
- Investigate the need for a separate best management practices strategy for spring runoff.
- Engage with comprehensive planning to encourage more concentrated development.
- Target community lakeshore planning such as multiple-landowner boat access under various water levels and least-impact marina siting.
- Investigate how to protect unfragmented habitat in northern Green Bay.
- Consider ways to engage and build community capacity.

Lake Sturgeon

- Continue restricted harvest.
- Ensure availability of spawning sites at dams under high and low water conditions through Federal Energy Regulatory Commission licensing.
- Protect hydrologic integrity of watershed for small rivers to maintain genetic diversity.
- Reduce runoff of suspended solids.
- Provide in-stream habitat improvement where possible and at critical sites.
- Develop innovations to pass fish upstream without passage of aquatic invasive species.
- Assess significance of egg predation.
- Assess success of downstream migrants passing over dams.
- Determine the restoration potential of macrophyte habitat for juveniles.
- Develop census techniques for juveniles 3 to 10 years old.
- Assess introduction of daughterless carp.

Benthic Community

- Continue current and proposed regulatory controls for nutrient and solids loading, biochemical oxygen demand, and non-persistent toxic substances.
- Complete and implement the lower Fox River TMDL.
- Update wasteload allocation rule (NR 212) to

determine need for adjustment resulting from climate change.

- Continue existing programs to restrict spreading of dreissenids and encourage regulatory activities aimed at preventing future invasions of exotic and invasive species.
- Develop rapid response planning and implementation methods to improve existing aquatic invasive species control programs.
- Develop riparian guidance for west shore area to control amount and type of artificial modifications to shoreline and runoff conveyance mechanisms.
- Establish a clear understanding of the ordinary high water mark.
- Consider dam removal or flow manipulation of the lower Fox River and other Green Bay tributaries.
- Continue existing programs for identification and remediation of legacy pollutants.
- Encourage low-impact development for future development in the watershed.
- Evaluate the potential benefits of a temporary Lake Winnebago drawdown.
- Investigate the possibility of isolating the Great Lakes from ocean-going vessels via cargo transfer.
- Encourage research and regulatory attention to compounds of emerging concern.
- Repeat the Green Bay Mass Balance Study PCB fate, transport, and food web modeling for post-climate-change conditions.
- Explore the utility of increased biofuel production (for example, switchgrass) from marginal cropland.
- Continue exotic and invasive species education/awareness programs for boaters, anglers, etc.

These lists of adaptive management strategies identified through separate conservation target focus groups are first-cut, raw ideas in need of sifting and winnowing, then refinement. Many of the strategies refer to ongoing programs, laws, policies, practices, etc., suggesting that to a large degree we are already doing the right things but need to do them better or to do more of them. The emerging, overarching adaptive principle appears to be: Reduce other non-climate stressors and thereby increase the resilience and adaptive capacity of the system. While this principle is not new, it is consistent with the sustainability mantra and within our grasp to accomplish.

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HUMAN HEALTH WORKING GROUP

Human health is affected by climate change through many pathways. These include heat-related morbidity and mortality; flooding and storms with associated trauma and mental health concerns; air pollution, especially from ground-level ozone and potentially from aeroallergens (for example, pollen and molds); and infectious diseases, particularly those that are water- or vector-borne. Adaptation to climate change health risk, therefore, will involve many different types of interventions.

However, some of the largest gains for public health may stem from a reduction in our dependence on fossil fuels, especially though improved air quality and green design of cities, which would promote a less sedentary lifestyle. The WICCI Human Health Working Group therefore recommends an integrated approach to risk reduction, whereby the distinction between greenhouse gas mitigation policies and adaptation strategies gives way to a solid continuum of prevention.

Our group also recommends that climate change risks not be viewed as an isolated threat. For example, weather-related health risks must be assessed in the context of land cover and other concurrent environmental stressors. The urban heat island effect and land cover that alters the rate of rainfall runoff (via impervious surfaces) will modify the intensity of potentially hazardous heat waves and intense precipitation events, respectively.

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Health Risks

State- or region-specific health risks identified by our working group include the following:

- Increase of ground-level ozone in the summer months by the end of the current century, translating into an increase in the number of exceedances of the current National Ambient Air Quality Standards (NAAQS) for ozone.
- Uniform increase of future summer temperature associated with more days beyond a threshold temperature (greater than the 95th percentile) and therefore more heat-related hospital admissions.
- Heavy rainfall events have increased considerably in frequency in the Midwest. These events will become up to 40 percent stronger in southern Wisconsin, resulting in greater potential for flooding and waterborne diseases from parasites, bacteria, and/or viruses.
- With regard to vector-borne diseases, warmer temperatures along with drought conditions may increase the number of cases of West Nile virus. However, if dryness dominates future climate scenarios, Lyme disease may be pushed northward into Canada; tick survival is suppressed in the Great Lakes region by the end of this century such that the risk in Madison could fall by over more than 15 percent.

Recommendations

In formulating and implementing a state climate change response plan for public health, the working group recommends that:

- The Wisconsin Department of Health Services work closely with the state Division of Emergency Management and other key agencies to incorporate climate change into the planning process and into final mitigation plans.
- The state expand activities of the Wisconsin Environmental Public Health Tracking program to include indicators of climate change.
- Planning should be toward sustainable solutions. For example, in the case of heat wave response plans, consideration should be made of the sources of electric power for air conditioning, with a strong preference for renewable sources such as wind or solar.

Policy-makers (at, for example, the Public Service Commission of Wisconsin) should carefully weigh the impacts of their infrastructure investment decisions on (a) human health and (b) the state's capacity to adapt to a changing climate. For example, water management facilities should be built to specifications for future intensification of rainfall events rather than simply considering current rainfall/runoff distributions.

The working group encourages greater regional coordination of plans and policies as well as more effective capacity-building at the local level. We also recommend the development of local and regional plans and policies that create more livable, sustainable and resilient communities. "Smart Growth" (in contrast to scattered sprawl) has potential benefits for human health, the economy and the environment. Complementary "green" land use practices (for example, planting street trees) could adaptively retrofit existing buildings, lots and neighborhoods. And "co-benefits" of multimodal transportation planning should be included in any cost-benefit analyses of responses to climate change.

MILWAUKEE WORKING GROUP

Climate change has the potential to impact urban centers in several different ways. On a statewide basis, climate scientists project that annual average temperature will increase by 4-9º Fahrenheit between now and 2050. In addition, they project that the frequency of heavy rainfall events will increase. The complexities of the urban environment make it difficult to anticipate potential consequences and long-term impacts that will result from these changes in climate. The Milwaukee Working Group was formed to examine aspects of the urban environment that may be sensitive to climate change and to identify adaptation strategies to minimize the negative impacts of those changes.

For this first assessment, the Milwaukee Working Group focused on three broad areas: water resources, urban infrastructure, and public health. The Milwaukee Working Group identified spring rainfall as the climate parameter that is likely to cause the greatest stress on water resources and urban infrastructure. The impacts on water infrastructure, roadways, and buildings resulting from these stresses are likely to have economic ramifications that are currently difficult to estimate. Scientists also expect climate change to adversely affect air and water quality. This is likely to affect public health. For example, the deterioration of air quality that is expected to result from climate change may exacerbate existing problems with childhood asthma in urban areas. This may be particularly important for Milwaukee, which already has the second highest rate of childhood asthma in the nation. In addition, the impacts of climate change may fall more heavily on some sectors of the population than on others such as in urban areas with high population densities and a broad range of socioeconomic conditions. For instance, the additional costs associated with air conditioning make it likely that the elderly and the economically disadvantaged will be more heavily impacted by heat waves than other sectors of the population.

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Water Resources

Water resources are vital to urban centers and are closely linked with economic vitality, human health and quality of life. Stormwater runoff is currently a major challenge in heavily developed areas due to their large amounts of impervious surfaces. Changes in rainfall patterns can impact flooding, water quality, and the infrastructure needed to meet stormwater regulations. In June 2008 and July 2010, extreme storm events that produced high-intensity rainfall caused extensive flooding. This overwhelmed sewer systems throughout Wisconsin, resulting in the release of untreated sewage into floodwaters. Such events highlight the vulnerability of the urban environment to high levels of precipitation. The WICCI Stormwater Working Group has said that it is premature to make significant changes in the design of stormwater infrastructure except where change is warranted by today's climate. The one exception is winter/spring rainfall, where model projections are fairly consistent. Rainfall-runoff modeling will be required to determine implications for watershed flooding.

Climate change may also alter the amount of groundwater recharge. Changes in the timing, amount, or intensity of precipitation may affect the amount of water available for recharge as well as the capacity of soil to accept water. Changes in temperature and humidity may alter the amount of water lost from soil through evapotranspiration, changing the amount of recharge. The resulting changes in recharge may affect both the availability of groundwater as a water supply source and the amount of discharge of groundwater to surface water bodies as baseflow.

Lake Michigan surface water is the major drinking water source for Milwaukee County. This water source may become more difficult to treat due to changes in biological or chemical contaminant loads that are a consequence of changing storm patterns and increased pollutant discharges into surface waters. Changes in water temperature or suspended solids may also affect treatability of source water and, depending upon the magnitude of these changes, could necessitate infrastructure improvements.

Photo: Milwaukee Metropolitan Sewerage District.

Floodwaters impact Milwaukee neighborhoods following heavy rainfalls, June 7, 2008. Kinnickinnic River, 9th Place and Cleveland.

Changing climatic conditions may stress wastewater infrastructure. Portions of Milwaukee are served by combined sewers, which convey both stormwater and sanitary sewage to wastewater treatment plants for treatment. Increases in the frequency and intensity of rainfall in spring months have the potential to overwhelm the capacity of this system, causing basement backups and/or combined sewage overflows. These events have public health implications resulting from the associated release of pathogens into buildings and surface waters. While the predictions for changes in the frequency of high intensity rainfall are modest, sewage contamination of homes and waterways is a serious issue and should be examined in depth.

Public Health

The projected changes in climate may result in adverse impacts upon public health. It is likely that some existing public health problems may be worsened. This is especially the case in urban areas like Milwaukee because these areas have high population densities and contain large numbers of people who are members of susceptible populations.

Air quality changes resulting from climate change are likely to produce public health impacts. Because heat is a factor promoting the production of ground-level ozone, the projected increases in temperature are likely to result in increases in the frequency at which concentrations of ozone at levels high enough to pose health risks to sensitive individuals occur. Exposure to these levels of ozone is associated with a number of health problems including decreased lung function, susceptibility to respiratory infections and reduced immune system function. Urban areas such as Milwaukee have high population densities, including populations susceptible to health problems.

The incidence of waterborne diseases such as gastroenteritis may increase as a result of potential impacts of the projected increase in the incidence of heavy storms. As noted above, urban flooding can overwhelm sewer systems, resulting in the release of untreated sewage into floodwaters in streets and basements. This may increase exposure to waterborne diseases. The projected increase in the incidence of heavy storms may also increase the potential for people to be exposed to pathogens through recreational water or drinking water. Currently, high concentrations of fecal indicator bacteria are routinely found in Milwaukee surface waters following rain events. While not all fecal pollution sources carry pathogens, these higher concentrations indicate a greater potential for pathogens to be present. A better understanding of the dynamics of how contamination enters surface waters would allow scientists to better characterize the risks of pathogen exposure associated with different storm event patterns and to assess how these potential risks may change with changing climatic conditions.

Mid-century climate projections for the Milwaukee area include an increase in the number of very hot days and higher nighttime low temperatures. This suggests that heat waves will become more frequent. Urban residents are particularly sensitive to the effects of heat waves. Urban areas experience a heat island effect because buildings, roads and other structures are efficient at absorbing and storing heat during the day and slowly releasing it during the night. Extreme heat can cause a number of heat-related illnesses, such as heat exhaustion and heatstroke that can result in death.

Infrastructure

Urban areas have large infrastructure needs that include roadways, sewers, and buildings. Climate change may have direct impacts on the lifespan or integrity of materials used in structures. Stressors such as changes in freeze-thaw cycles may decrease the durability of roads, bridges or buildings. Climate change may also influence the design requirements. "Green" infrastructure that includes rain gardens and green roofs not only helps alleviate stormwater and urban heat island effects today but may also contribute to the resilience of the urban area in the face of changing climate.

Research Needs

The initial focus of the Milwaukee Working Group in 2008-2010 has been on water resources and the linkages to public health. Several research studies are underway that include assessing how the number and magnitude of combined and separated sewage overflows may change due to changes in storm frequency and intensity. We are also exploring the impact on the water quality of rivers and the potential changes in nearshore circulation patterns in Lake Michigan. The Milwaukee Working Group has identified immediate needs for detailed analyses of vulnerabilities and associated risks to flooding, air quality and concrete structures. An assessment of economic impacts due to climate change is of high importance as this information will be needed in weighing the costs of adaptive strategies against potential risks.

Adaptation

The Milwaukee Working Group is focusing on identifying "no regrets" adaptive strategies such as practices or policies that have little or no cost but would aid in adaptation. Developing adaptation strategies in response to climate change requires a comprehensive, multidisciplinary approach involving all stakeholders and taking into account that our knowledge of climate change impacts is limited but evolving rapidly. A step-by-step approach should be taken to be most effective.

We suggest:

1. Involving stakeholders in the process of identifying vulnerabilities and developing adaptation strategies.
2. Performing detailed analyses of sensitivities and risks.
3. Identifying and implementing adaptation strategies.
4. Implementing monitoring to determine the extent to which climate components have been incorporated into management decisions and the actual environmental impact of climate change and adaptation projects.

The Milwaukee Working Group does not yet recommend any specific adaptation strategies; however; we include below some examples of adaptation strategies that other major metropolitan cities have identified.

Stormwater/flooding

- Conduct public education on water usage, rain barrels and rain gardens.
- Examine capacity of sewers and/or pursue alternative operational procedures for wastewater treatment plants.
- Apply stormwater best management practices: stormwater retention, green infrastructure practices such as permeable pavement, rain gardens and buffer strips.

Air Quality

- Increase tree canopy.
- Increase transportation alternatives.
- Increase use of cogeneration for power production.
- Decrease use of carbon fuels.

Public Health

- Improve warning system for extreme weather events and air quality advisories.
- Conduct public education on climate-related health threats to urban areas.

Built Environment

- Improve energy efficiency of buildings and homes.
- Apply green infrastructure: green roofs and high-albedo surfaces.
- Ensure buildings, roads, and bridges can withstand extreme weather events.

PLANTS AND NATURAL COMMUNITIES WORKING GROUP

The warming of Earth's climate system is unequivocal, as evidenced by increases in global average air and ocean temperatures, extensive melting of snow and ice, and the increasing global average sea level. The evidence from a wide variety of plant species and communities shows that warming is strongly affecting natural biological systems. The ability of plants and natural communities to respond to climate change will depend in part on the rate and magnitude at which climate change occurs. Different species, populations, and individuals migrate and disperse at different rates, and land use patterns will complicate ecosystem adaptation to climate change by hindering migration. The synergism of rapid temperature rise and other existing stressors could easily disrupt the connectedness among species, leading to the reformulation of species communities.

In Wisconsin as well as globally, climate change is likely to result in a reduction of biological diversity through the extinction of individual species, the displacement of others, and the disruption of species interactions. Recognizing and adapting to these changes may help maintain important ecological, biological, and social functions and values. To assess the impacts of climate change on plants and natural communities, the Plant and Natural Community Working Group (PNC), composed of scientists from the University of Wisconsin-Madison and state and federal agencies, developed a matrix of impacts that could affect groups of natural communities (Table 1). The impacts were not meant to be all-inclusive but rather to include many of the major impacts that could result from climate change. We chose six impacts (pollination, range shift, disaggregation of species within natural communities, invasive species, fragmentation, and change in fire regime) to scrutinize more closely. This approach is not meant to diminish the importance of the other impacts but is instead an opportunity to scrutinize selected impacts in greater detail.

Pollination

Scientists have observed substantial shifts in flowering phenology -- the timing of biological events over the course of a year -- that have the potential to disrupt the relationships that plants have with the animals, fungi,

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and bacteria that act as pollinators, seeds dispersers, predators, herbivores, and pathogens. Climate change could directly disrupt or eliminate mutually beneficial interactions like pollination between species. Southern upland forests, savannas, barrens, grasslands, and northern and southern wetlands could be moderately to greatly impacted by climate change. Due to their species composition and structure, it seems likely that impacts may be low in the remainder of the community groups.

Range Shift

Many of the rare and native plant species are at the edges of their distributional ranges in Wisconsin and are often more abundant outside of the state. The response of species to a rapidly changing environment is likely to be determined largely by population responses at range margins. Isolated or peripheral populations of common species and rare species may be the first of Wisconsin's flora to show the effects of climate change because they occur more sporadically and often occupy less suitable habitat. The rate of migration will depend on a number of factors including dispersal barriers, suitable habitat for germination and establishment, and seed dispersal capabilities of the species. Climate change may affect not only individual species but also their associated natural communities that are on the edge of their range.

Disaggregation

Climate change will likely fundamentally transform Wisconsin's ecological communities and landscapes. Some may change so much that they will disappear or disaggregate, being replaced by "novel" communities. The distribution and abundance of each species is governed by its unique sensitivities to climate, local physical variables such as soil characteristics and topography, interactions with other species, and human action. The problem of climate-driven community disaggregation and formation of "novel" ecosystems poses a fundamental challenge to efforts to steward Wisconsin's natural resources. We have a very limited capability for predicting the indirect effects of climate change, for example, those in which climate change affects communities by mediating existing interactions among species or by enabling new interactions among newly associated species within novel ecosystems.

Invasive Species

Invasive species, pathogens, and insect pests have long been recognized to have substantial human health, economic, and ecological impacts on the flora of North America. Increased carbon dioxide levels and nitrogen deposition could drive changes in ecosystem nutrient cycling that make such a system more vulnerable to invasive species. While some effects of invasive species might be more direct and obvious, such as com-

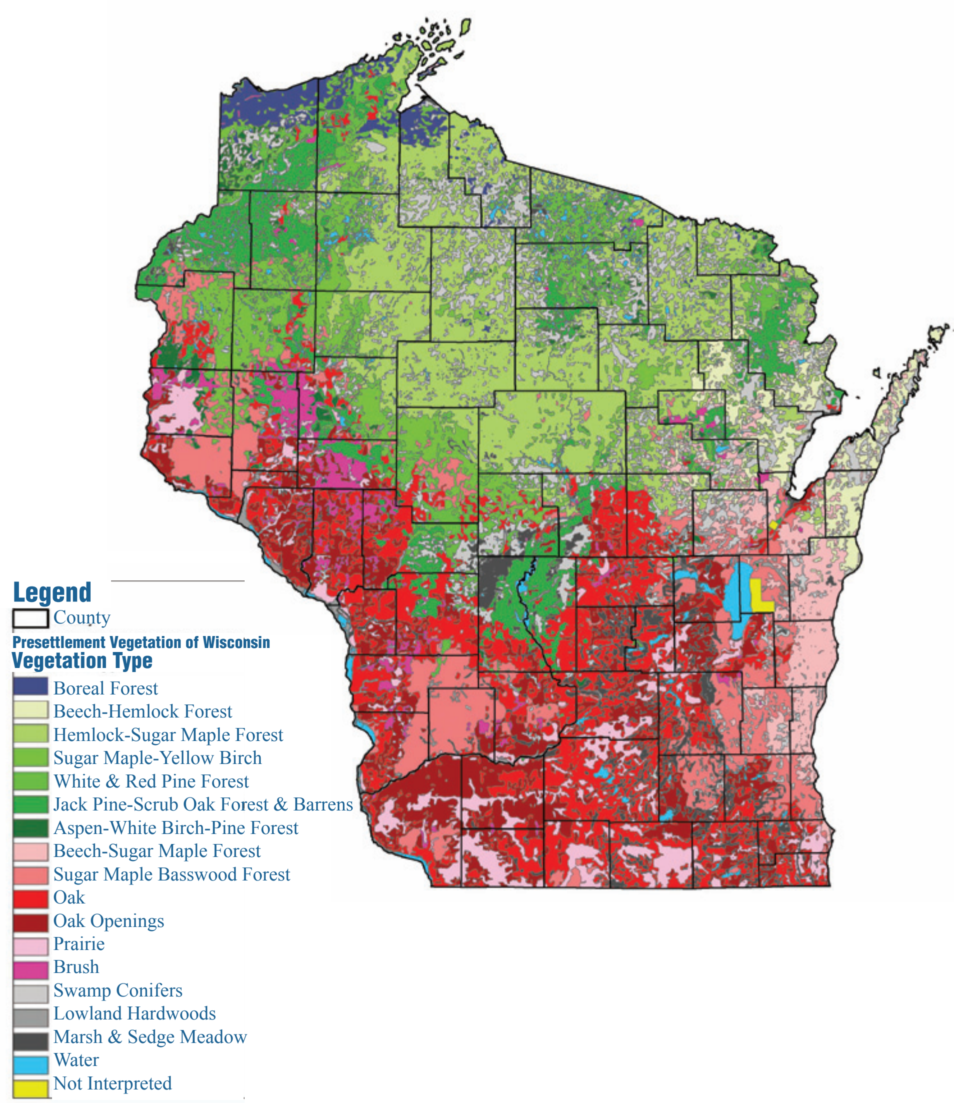

Figure 1. Early vegetation of Wisconsin.

petition, displacement, and usurpation of pollinators and other resources, others might be more unobtrusive. Climate change effects from invasive species, pathogens, and insect pests may pose moderate to high risks for all of the natural community groups in Wisconsin.

Fragmentation

The intricate mosaic of the natural communities of Wisconsin has greatly changed since statehood (Figure 1). Widespread urbanization, the development of a complex road network throughout the state, conversion for agricultural purposes, and other alterations that affect natural communities have resulted in a wholesale fragmentation of the natural landscape (Figure 2). Species in landscapes that are more intact with connected patches of suitable habitat might fare better than those that are in landscapes that have significant barriers to dispersal. Climate change could moderately to highly affect all of the natural community groups (Table 1). The combination of climate change and increased fragmentation could affect species and natural communities statewide. Reducing fragmentation and increasing connectivity could reduce the peril for some plant species.

Change in Fire Regime

Climate influences fire regimes in two ways: directly, by influencing weather patterns conducive to fire ignition and spread, and indirectly, by influencing plant communities through temperature and precipitation trends that favor or discourage fire-adapted plant species. Changes in fire regime could be most apparent for the most fire-prone natural communities, particularly in landscapes not fragmented such as the jack pine-dominated barrens in central and northern Wisconsin. Increased potential for fire may benefit certain community groups like grasslands (for example, dry prairies), savannas and barrens (for example, oak woodlands, oak and pine barrens), and some communities within the northern and southern wetlands (for example, sedge meadows). Increased potential for fire may be detrimental to communities within other groups. Fire on the Wisconsin landscape has been limited by human control practices that focus on human safety and property.

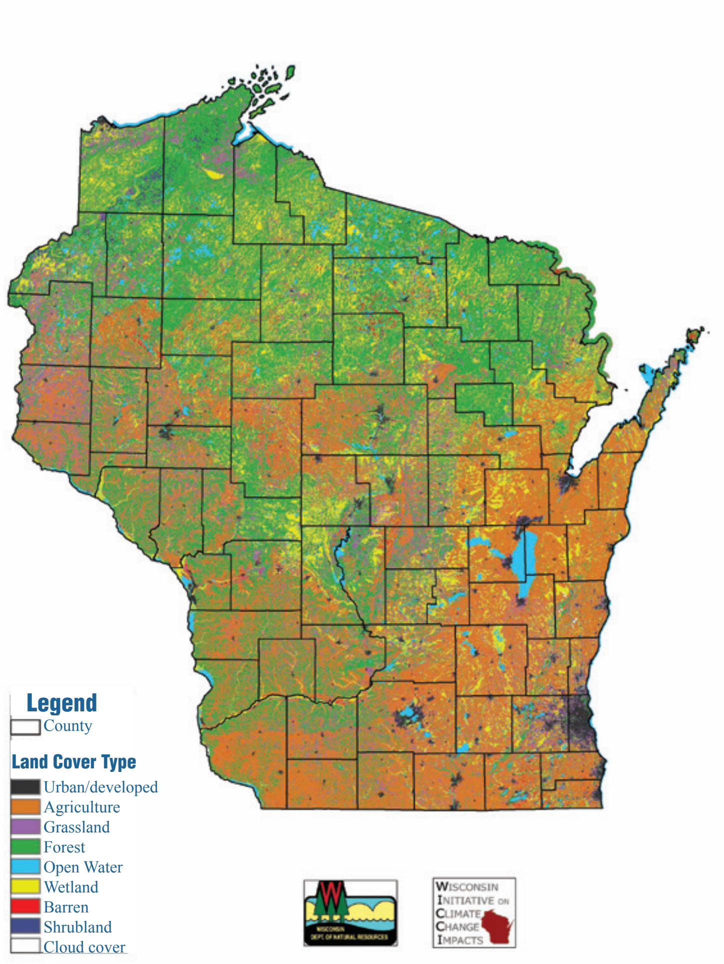

Figure 2. Land cover in Wisconsin.

Adaptation Strategies

The initial adaptation strategies for the WICCI Plants and Natural Communities Working Group are, by necessity, fairly broad, in part because this is the first step in the long-term process of developing risk assessments for individual species and natural communities. Many aspects of the interactions and biology are not known, thereby making recommendations for specific plants or communities difficult. Here the PNC lays out a framework by which we will develop comprehensive plant species and natural community adaptation strategies.

Adaptation actions can be categorized in three groups. First, **resistance** adaptation actions are defensive actions intended to resist the influence of climate change; they are intended to forestall impacts and protect highly valued resources. Second, **resilience** actions improve the ability of ecosystems to return to desired conditions after disturbances. Finally, **response** or facilitation actions help facilitate the transition of ecosystems from the current to new conditions. The following adaptation strategies can be in more than one of these categories:

1. **Risk Assessments**
While it will clearly be impossible to eliminate uncertainty, to help reduce the amount of uncertainty in making decisions about resource allocations, risk assessments will be made of the vulnerability of individual species and natural communities to changing environmental conditions based on climate projections. The assessments could be used in prioritizing

IMPACT	Northern Upland Forests	Northern Lowland Forests	Southern Upland Forests	Southern Lowland Forests	Savannas & Barrens	Grasslands	Northern Wetlands	Southern Wetlands	Great Lakes Shore	Aquatic	TOTAL
PHENOLOGICAL & RELATED CHANGES											
Pollination	1	1	2	1	3	3	2	2	3	1	**19**
Shifts in dispersal	1	0	2	0	0	0	0	0	0	3	**6**
Early bud burst	2	0	2	0	0	0	0	0	0	0	**4**
BIOTIC/ABIOTIC FACTORS											
Range shift	3	3	2	2	0	0	2	3	2	1	**18**
Community disaggregation	3	3	3	3	3	3	3	3	3	3	**30**
Invasives/diseases/pests	2	2	3	3	3	3	2	3	2	3	**26**
Fragmentation/isolation	2	2	3	3	3	3	2	3	2	3	**26**
Herbivory	3	3	3	3	2	1	2	2	0	0	**19**
Soil distribution	1	0	1	0	0	0	1	3	0	0	**6**
FIRE											
Change in fire frequency/intensity	3	1	2	1	3	3	1	1	0	0	**15**
WEATHER IMPACTS & EXTREME EVENTS											
Change in frost dates	2	2	0	0	0	0	0	0	0	0	**4**
Extreme winter	0	0	2	2	0	0	0	2	0	0	**6**
Increased evapo-transpiration	1	1	1	0	0	0	3	3	0	0	**9**
Ice storms	3	1	1	1	0	0	0	0	0	0	**6**
Droughts (hydrology)	1	3	2	3	0	2	3	3	3	3	**23**
Floods & wetlands	0	2	0	3	0	2	3	3	3	0	**16**
Scouring (water, ice)	0	3	0	3	0	0	0	0	2	2	**10**
TOTAL	**28**	**27**	**29**	**28**	**17**	**20**	**24**	**31**	**20**	**19**	

Table 1. Comparative climate change impacts on different natural community groups. The scale for impact levels is 0-3, with 3 indicating the greatest impact.

management and other adaptation actions. It is anticipated that vulnerability assessments resulting from the PNC Working Group would be useful for other WICCI working groups, including Forestry and Wildlife. Risk assessments can lead to short- and long-term decisions and can contribute to the resistance, resilience, and response categories.

Evaluation of existing sites for buffers, connectivity, management needs, and other factors can point toward appropriate actions and allocation of resources. Small sites that have a high concentration of rare species with limited habitat availability may need additional buffers surrounding the sites to reduce the influence of external stressors. Early response to invasive species may be critical for such sites.

Recognizing that resources are and will likely continue to be limited for conservation actions, site analyses can be used to prioritize decisions about land acquisition or easements. If two sites are roughly the same size but one is relatively uniform in natural community types and distribution and the other has greater complexity due to factors like topographic relief, the latter property may have longer-term conservation value. The more heterogeneous and complex a site, the more microhabitats are likely present that can meet more habitat and other requirements for a wide range of organisms.

A landscape evaluation would include many of the factors listed above but especially look at connectivity between sites and the range in size of individual sites in the landscape. The results of a larger-scale analysis can identify opportunities to collaborate among units of government and private landholders; it may also be able to suggest cross-border actions with neighboring states. A landscape assessment would also examine the degree of redundancy of sites because redundant sites can help spread risk instead of depending on only one or a few high-quality sites.

An analysis of connectivity at landscape levels can identify important long-term opportunities for conservation actions. Depending on the species, its ability to disperse, and the relative permeability of the matrix, connectivity may not be as important for long distance dispersal as for other aspects of connecting sites. Corridors of natural habitat along natural environmental continuums can provide room for movement and provide favorable conditions for local adaptations.

2. **Protection and Management**

Existing conservation properties should be evaluated, both on a local, individual basis as well as in a landscape context. Assessments of individual sites would include an analysis of size, surrounding land use and degree of buffer, site heterogeneity and complexity, site integrity, exposure to external stressors, current management regimes, and connectivity to other local sites. After evaluations are completed, management activities can be prioritized. For example, if an external stressor is identified as invasive species, property managers could work to reduce or eliminate the invasives, thereby contributing to the resistance and resilience of the property. Opportunities that were identified in the evaluation could lead to the protection of additional property by public or private organizations that increase the buffer or connectivity of the property.

Once adaptation actions have begun, it is important that researchers and land managers are able to determine the effectiveness of those actions. Monitoring, both on the ground and using remote imagery, will help guide adaptive management decision-making. Adaptive management can help in the short and intermediate term (resistance and resilience) as well informing response actions for the longer term.

3. **Assisted Migration**

The actions above are well-established and widely applied in conservation biology. Other proposed actions, however, are much more divisive. One such proposal that is being widely debated in the conservation community is that of assisted migration, the idea that plants and animals should be moved geographically ahead of the projected wave of climate change. Rather than being a resistance or resilience action, assisted migration would be considered a facilitation action and therefore perhaps be considered for the long term. Again, because we lack basic biological information about many species, including those that are rare, assisted migration may create more problems than they solve. It is probable that if assisted migration is deemed an appropriate measure, decisions will have to be made on an individual species basis.

SOIL CONSERVATION WORKING GROUP

Conservation of the soil resource in Wisconsin is not a new challenge but one that will become more difficult based on predicted climate changes. Our long-term goal, even in the face of a changing climate and new demands on the land, should be to eliminate sediment and phosphorus impairments of our surface waters and to maintain the potential productivity of Wisconsin's soil resource. We believe that soil conservation and water quality are compatible with current and emerging expectations of Wisconsin's farmlands, **provided that practices we largely know how to do are widely adopted by our farmers.**

Soil particles eroding from agricultural lands both degrade the soil resource, potentially reducing agricultural productivity, and pollute rivers and streams, which impacts Wisconsin aquatic ecosystems. Decades of technical, educational, and financial assistance to land managers have in many places substantially reduced this form of runoff pollution. However, progress is often slowed or stalled by decreases in government attention and oversight and by evolving agricultural practices for both food and fuel. Recently, rising demand for agricultural products and changing precipitation patterns have threatened to eliminate or even reverse progress toward minimizing soil erosion impacts on water quality.

The United States Department of Agriculture-Natural Resources Conservation Service conducts the National Resource Inventory (NRI) to assess land use and soil erosion across the nation. Results indicate that while progress was made in Wisconsin from 1982 through 1997, losses from soil erosion are now increasing

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(Table 1). The soil erosion phenomenon is enormously complex, but lands being converted from perennial vegetation to row crops and climate change are both likely contributing to this increase.

YEAR	AVG. SOIL LOSS (TONS/(ACRE*YR))
1982	4.64±0.13†
1987	4.11±0.08
1992	3.88±0.11
1997	3.72±0.08
2002	4.19±0.16
2007	4.44±0.25

†mean±standard deviation

Table 1. Sheet and rill erosion averaged across Wisconsin.
Source: USDA-NRCS-National Resource Inventory.

A relatively small fraction and number of precipitation events each year cause most of the annual soil loss from agricultural fields. There is evidence that highly erosive precipitation events are increasing in frequency, and climate change models predict intensification of the hydrologic cycle in the future. Simulation models that combine future climate conditions with soil erosion calculations indicate that in the absence of appropriate adaptation actions, soil erosion in Wisconsin could more than double by 2050 compared with the 1990s.

At the core of soil conservation in Wisconsin and the United States is voluntary adoption of appropriate practices by farmers. Beginning in the 1930s the federal government became engaged in the problem through research, demonstration, education, and financial and technical assistance to individual farmers. To this day governments at the federal, state, and county level provide technical assistance, such as engineering design and consultations, and financial incentives, known as "cost-sharing." As in the 1930s, individual farmers differ remarkably in their willingness to adopt soil-conserving behaviors. The state of Wisconsin has some limited power to intervene in the face of egregious soil erosion, but this is rarely exercised.

Three levels of government as well as civil society are involved in soil conservation. The government agencies engaged in encouraging soil stewardship in Wisconsin are the United States Department of Agriculture-Natural Resource and Conservation Service (NRCS); Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP); Wisconsin Department of Natural Resources (DNR); and Land Conservation Departments based in county governments (LCDs). Increasingly, civil society organizations, such as the River Alliance of Wisconsin and Trout Unlimited, are playing a role in connecting farmers with government-provided assistance and cost-share funds. The roles and relationships of these actors overlap and slowly evolve with changing laws.

Given the contexts of changing hydroclimate and increased demand for agricultural commodities, reducing soil erosion and the resulting impacts on aquatic ecosystems will likely require greater focus on implementation and maintenance of both structural soil conservation practices, such as terraces or grassed waterways, and non-structural practices like conservation tillage. This work, in turn, depends on government commitment to human resources, data resources, and ongoing monitoring; better tools for cost-benefit analysis, and the political will to both enforce existing regulations and set higher standards for protection of soil and water resources.

Adaptation Strategies

Our adaptation strategies seek to **adjust and strengthen the public-private collaboration that since the 1930s has been central to minimizing soil erosion.** Experience demonstrates that land managers hold a wide range of attitudes about their roles in stewardship of soil and water resources. Today's agricultural economy often forces farmers to make short-term decisions that may be necessary for survival of their business but are not protective of soil and water resources. Additionally, a substantial fraction of Wisconsin croplands (about 30 percent in 2007) is now leased on short-term contracts, so operators lack incentives for investments in soil conservation.

Our adaptation strategies address what we believe are four major components of any soil conservation effort: ***strategy***, ***practices***, ***monitoring***, and ***evaluation***. ***Strategy*** includes planning processes, goal-setting and metrics used to determine success, allocation of human and financial resources, and the roles and relationships ascribed to government and civil society institutions and land managers. ***Practices*** refer to the agronomic and engineering practices prescribed as soil-conserving and the degree to which they are adequate to reach the goals of the conservation program. ***Monitoring*** seeks to determine the extent of the adoption of soil-conserving practices and the degree to which desired outcomes are met. ***Evaluation*** is essential for a rich and informative assessment of programs aimed to increase compliance and seeks to provide insight into the relative importance of strategy, practices, and monitoring to achieving compliance. We found that this framework assisted us in granting appropriate attention to the diverse issues that appear relevant to adapting soil conservation to a changing climate.

1. Strategy

- **Develop new metrics for sustainability of soil and water resources**. The current standard for tolerable soil loss, the soil-specific value of T, has long been debated. It arguably represents a compromise between what will actually sustain the soil resource and what is thought to be achievable practically. Additionally, assigned values of T are generally not adequate to meet current water quality standards. For the time being, however, we must continue to use T as an interim goal while new metrics are explored.

- **Fully utilize and expand cross-compliance provisions and recognize that additional regulatory tools are required.** Cross-compliance refers to legal provisions requiring that landowners who receive government benefits (for example, crop price supports or preferential tax treatment) meet specified soil conservation goals. It is not clear that all of these obligations are met at present. Additionally, new regulatory tools are needed to improve our ability to identify and target poorly managed lands.

- **Provide the human resources necessary to facilitate broad adoption of the practices we know can reduce soil erosion and to ensure compliance with existing rules.** Implementation and compliance assurance of soil conservation programming is labor-intensive. Counties consistently cite lack of staffing as the first impediment to greater success in broadening adoption of soil conservation.

- **Revisit public policy surrounding subsidies for soil conservation practices.** The provision of financial incentives for land managers to follow some practices (and so avoid others) has a long tradition in soil conservation efforts at the federal, state, and county levels. How much other sectors of the economy should pay farmers (or contribute to costs) through cost-share programs is a challenging philosophical question. There is no right or wrong answer, but the debate should be revisited regularly.

- **Expand watershed-based programming efforts, with appropriate targeting of hydrologic units, farms, and fields.** A targeted watershed strategy places highest priority on water bodies that most urgently need improved soil and water conservation, then further focuses resources on lands in the watershed that most affect water quality.

2. Practices

- **Expand adoption of accepted soil-conserving field practices.** Our current toolbox of practices has the potential to handle the increased erosion rates that would accompany predicted hydro-climate changes. However, they are not nearly fully utilized.

- **Research strategies for objectively and efficiently identifying portions of the landscape that should be maintained in healthy, full-cover perennial vegetation, and develop programs to encourage returning these areas to this condition.** Specific portions of the landscape contribute disproportionately to water quality degradation. Planting perennial vegetation in these areas may be by far the best strategy for eliminating the pollution from them. While the Conservation Reserve Program seeks to eliminate tillage on these highly erodible parts of the landscape, contracts last at most 15 years. There is potential in developing alternative enterprises such as bioenergy feedstocks or managed livestock grazing.

- **Undertake research to enable more inclusive accounting of the costs and benefits of soil management choices.** Research in soil conservation to date has focused on the erosion-productivity relationship and the efficacy of practices at reducing erosion. In the face of climate change we need to broaden our understanding of the costs of soil erosion in terms of greenhouse gas and energy balances.

3. Monitoring

- **Develop systematic, transparent, and accessible monitoring programs for soil conservation and its impacts on water quality**. Soil conservation is a spatially distributed, temporally dynamic endeavor. Understanding what managers are doing across the landscape is a large challenge, but such data are essential both for checking on compliance with legal agreements and for subsequent evaluation of conservation programs. Currently available data are inadequate to for us to know what we are doing well and where our greatest failings are.

4. Evaluation

- **Conduct more evaluation work related to soil conservation.** The substantial public expenditures, institutional complexity, and evolving hydro-climate and policy contexts of soil conservation justify greater effort in understanding what works and why. The tools of evaluation should more frequently be brought to bear on soil conservation challenges.

- **Initiate an ongoing analysis of how bioenergy policies and changing production practices influence efficacy of soil conservation programs.** An important driver of vegetation management on the landscape will continue to be bioenergy markets and policy. Effects of these markets and policies on soil conservation should be given as much attention as changing hydroclimate.

Summary and Conclusions

Soil conservation is a complex biophysical, social, and economic challenge. Recent measurements indicate that soil erosion losses are increasing, probably caused by a combination of cropping system changes, relatively erodible land being returned to cultivation, and, perhaps, changing hydroclimate. The major interactions in play are diverse and interconnected (Figure 1). Climate change, both in temperature and precipitation, has direct negative impacts on soil conservation, but new cropping options opened by changes in growing-season length and temperature could conceivably contribute in positive ways. Expanded opportunities for bioenergy production from croplands have both potential negative and positive impacts. Greater market value from perennial plantings has the theoretical possibility of encouraging this choice on erodible lands. However, residue removal, expanded cropping onto highly erodible lands, and displacement of hay crops by annual crops can increase erosion.

Conservation research, education, and policy have the potential to improve soil conservation by broadening the range of options available to land managers. New conservation reserve programs in a context of comprehensive enforcement of existing regulations might reduce cultivation of highly erodible lands. Perhaps land grant universities must return to programs of research, demonstration, and education on soil conserving practices.

While climate change and bioenergy endeavors appear on balance to negatively impact soil conservation, many on-the-ground practices and policy decisions can prevent these issues from exacerbating soil erosion. The richness of this complex field promises as much opportunity as reason for concern—we have the ability to adapt soil conservation to a changing climate.

STORMWATER WORKING GROUP

Stormwater Management in a Changing Climate: Managing High Flow and High Water Levels in Wisconsin

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Climate change in Wisconsin is likely to increase the severity and frequency of high flows and high water levels. Our analysis of downscaled climate projections suggests that Wisconsin precipitation is trending toward wetter conditions and more intense rainfall.

Climate models also predict increases in cold season precipitation and increases in the ratio of rainfall to snowfall, potentially increasing the frequency of damaging flooding from rivers, lakes, and groundwater.

As a result of these changes we expect increases in the magnitude and frequency of high flows in streams and rivers, and high water levels in streams, rivers, lakes and impoundments.

Engineers have traditionally used historical precipitation and runoff data to design and evaluate infrastructure to manage the risks associated with precipitation to acceptable levels. Unless we modify the planning, design and management of this infrastructure to account for climate-mediated changes in precipitation, we will face greater-than-expected damages from high flows and water levels.

This is the first written report of the Wisconsin Initiative on Climate Change Impacts (WICCI) Stormwater Working Group. Members of this group include engineers, planners, utility operators, local government officials, state regulators, and academic researchers. This report provides background on the design of infrastructure and management practices used to manage high water conditions, discusses potential changes in Wisconsin climate based on historical data and downscaled climate model results, and presents specific adaptation strategies that recognize the large uncertainties in climate predictions.

The WCCI Stormwater Working Group believes that scientific knowledge about the potential increase in magnitude and frequency of precipitation is sufficient to warrant immediate changes in the methods we use to plan, design, and manage stormwater-related infrastructure. While the list of specific climate impacts is long and growing, we focus on three main areas for this report:

1. More frequent and severe rural stream and river flooding caused by increased rainfall, and shifting precipitation patterns that favor more rain during periods of low infiltration and evapotranspiration.

2. Increased occurrence of inland lake flooding resulting from increased precipitation in winter and spring.

3. Groundwater flooding caused by rising water tables due to increased cold-weather precipitation and increased variability in frost conditions.

With respect to the factors affecting high water conditions, WICCI's statistically downscaled climate projections for Wisconsin vary by climate model. However, those projections do support the following generalizations:

1. Modest increases in the magnitude of intense precipitation events are expected during the 21st century. For example, averaged over the state, the magnitude of the 100-year, 24-hour storm event (5-7 inches) is expected to increase by about 11 percent by the 2046-2065 time period.

2. Total precipitation and heavy precipitation events are projected to increase significantly during the winter and spring months of December through April. This combination of more precipitation and more intense events has the potential to cause more high water events.

3. The amount of precipitation that occurs as rain during the winter months of December to March is also projected to significantly increase. Winter rain can create stormwater management problems (for example, icing) and increase the risk of high water events during a season when rainfall does not normally occur in Wisconsin.

Unless appropriate adaptation strategies are adopted, we can expect increases in the frequency and severity of the following high water impacts:

- Erosion of slopes during intense rainfall events, resulting in high sediment and phosphorus loads to streams, rivers, lakes, and wetlands.
- Degradation of aquatic habitat as a result of manure runoff from fields and drain systems.
- Impairment of roadways and bridges washed out due to high water or slope failure.
- Groundwater flooding of property and cropland.
- Contamination of rural residential wellheads as a result of surface water and groundwater flooding.
- Flooding of urban streets and homes due to inadequate runoff drainage systems.
- Failure of impoundments, levees, and stormwater detention ponds.
- Failure of rain gardens and other biofiltration best management practices (BMPs) due to prolonged periods of saturated soils.
- Stormwater inflow and groundwater infiltration to sanitary sewers, resulting in untreated municipal wastewater overflowing into lakes and streams.

The WICCI Stormwater Working Group has identified specific actions that can be taken to build capacity in Wisconsin to adapt to the challenges of our changing climate. Many of these adaptation strategies are steps that ought to be taken today as part of the continuing improvement of the water resource management professions. Many of the specific management recommendations are good public policy in any climate.

High Water Adaptation Strategies

Traditional design and management strategies for high water conditions assume that the climate is not changing. However, analysis of historic climate data and predictions by climate models indicates that Wisconsin's climate is changing and will continue to change. Unless our design and management strategies adapt to changing climate conditions, using traditional approaches will lead to the risk of significant increases in economic and environmental damage.

The WICCI Stormwater Working Group recommends the following adaptation strategies that can lead to increased societal capacity to minimize risk from high water conditions:

Assessing Site-specific Vulnerabilities

We recommend that local units of government be provided the technical and financial assistance needed to assess and mitigate their vulnerabilities to potential high water conditions caused by present and future climate.

Closing Regulatory Gaps

We recommend that the state of Wisconsin work with municipalities and counties to develop minimum design and performance standards for the control of the high water impacts of development. We further recommend that these standards specify that regulatory control extend to the 100-year storm event and require regular updating with the most recent rainfall statistics. Consideration should also be given to requiring additional stormwater storage capacity to account for uncertainties in future rainfalls.

We recommend that the Wisconsin Department of Natural Resources develop an approval process for prior-converted croplands that are being removed from agricultural use that will encourage their restoration and prevent development in flood-prone areas. We also encourage county and municipal governments to adopt an approval process or place land use controls on development that occurs on hydric soils in areas that are likely to experience future flooding.

Climate Monitoring and Modeling

We recommend that Wisconsin's climate monitoring network of cooperative weather stations, stream gauges, and groundwater monitoring wells be improved and maintained to provide continued high quality data to support short- and long-term climate impact modeling. Specific information needed to address climate impacts includes the following:

- Fine-scale rainfall data using calibrated National Weather Service precipitation and radar measurements.
- Real-time stream flow data from an expanded U.S. Geological Survey stream gauge network.
- Groundwater-level data from strategically placed observation wells to enable identification of vulnerability to groundwater flooding.
- Detailed understanding of sub-watershed characteristics to improve runoff and flood modeling.
- Geospatial data for drainage districts to identify vulnerability to increased high flows and groundwater levels.
- Location of high-risk and vulnerable practices in flood-prone areas, such as hazardous materials and petroleum storage, drinking water wells, and septic systems.

Building Technical Capacity

We recommend that the state develop and implement a long-term plan for developing continuous hydrologic simulation models of stream flow for critical watersheds. When appropriate, the models should be coupled to groundwater models. Participants in such modeling could include the Wisconsin Geological & Natural History Survey (WGNHS), the U.S. Geological Survey (USGS), the Southeast Wisconsin Regional Planning Commission, and private consulting firms.

Research

We recommend an investment in research at the state and national levels to build capacity and provide knowledge in the areas of winter/spring hydrology, hydrologic modeling, and decision-making under uncertainty for water resource management.

Stakeholder Action To Build Adaptive Capacity

The WICCI Stormwater Working Group has also identified specific actions that can be taken by water resource system stakeholders that will lead to an increase in our ability to adapt to our changing climate.

Regulators

- Revise local building standards to address runoff control.
- Base design standards on updated rainfall statistics.
- Require standby power for buildings with sump pumps to avoid flooding caused by storm-related power outages.
- Incentivize behavior change through fees and credits.

Planners

- In areas that are internally drained or have hydric soils, coordinate with regulators to assure that future land use changes do not increase flood vulnerability.
- Create or designate new surface flood storage areas (for example, wetlands) to mitigate high water impacts.
- Use updated models to predict groundwater impacts on development.
- Periodically update estimates of high water profiles based on revised rainfall data.
- Identify at-risk stream crossings and develop maintenance and high water contingency plans.

System Designers

- Coordinate the design of sanitary and stormwater systems to minimize high water impacts.
- Identify high-hazard areas and apply more stringent design criteria.
- Anticipate groundwater impacts on bio-infiltration best management practices (BMPs).
- Increase wastewater system peak flow management capacity and minimize stormwater inflow and groundwater infiltration.
- Use low-impact design to minimize runoff from newly developed areas.

System Managers

- Upgrade urban storm drainage systems based on continuous hydrologic modeling and climate predictions.
- Manage to minimize high-flow impacts rather than sediment removal during high storm flows (for example. bypass stormwater bio-infiltration BMPs).

- Assess impacts of high-flow events on sewage treatment plant process viability, and evaluate impacts of bypassing high storm flows around treatment plants' biological processes.
- Flood-proof vulnerable buildings and infrastructure.
- Build capacity for drinking water quality emergency assessment and response.

Educators

- Conduct public and technical education programs on climate impacts and adaptation.
- Educate communities about the hazards of building in areas prone to high water.
- Educate property owners about sanitary sewer inflow prevention.
- Encourage conservation tillage, stream buffers, and other low-impact agricultural practices to minimize rural runoff.

Securing Long-Term Capacity

Building adaptive capacity among this diverse group will require a sustained effort. The water resource management profession needs organizational support to integrate disciplines, knowledge, and implementation through a multidisciplinary effort involving academics, outreach educators, private-sector design professionals, municipal engineers, and other resource managers to:

- Facilitate communication among water resource management disciplines.
- Be a source of credible information on climate change for communities, the public, and practitioners.
- Be an authoritative voice to policy-makers and the private sector on climate adaptation strategies.

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Wisconsin's water resources are an important part of what defines us as a state and as a people. The Mississippi River, Lake Superior, and Lake Michigan help define our borders, and the 84,000 miles of streams, 15,000 lakes, 5.3 million acres of wetlands, and plentiful, though finite, supply of groundwater support industrial and agricultural activities and enrich our recreational opportunities.

Wisconsin's climate is changing (Kucharik, 2010), and our water resources are changing, too. Many aspects of our water resources respond to climate and can serve as indicators of climate change at various temporal and spatial scales. Analysis of historical data shows that water resources are intimately linked to local and regional climate conditions. Long-term records of lake water levels, lake ice duration, groundwater levels, and stream baseflow are correlated with long-term trends in atmospheric temperature and precipitation.

We anticipate that future climate projections will affect our state's water resources in both quantity and quality. Our working group cautions, however, *that there may be different hydrological responses to climate change in different geographic regions of the state*. This is clearly evident in analysis of past trends in Wisconsin and probable future climate projections. The differences reflect variations in land use, soil type and surface deposits, groundwater characteristics, and runoff and seepage responses to precipitation.

Goals of Adaptation Strategy

The Water Resources Working Group (WRWG) includes 25 members representing the federal government, state government, the UW System, the Great Lakes Indian Fish and Wildlife Commission, and the Wisconsin Wetlands Association. Members are considered experts in the fields of aquatic biology, hydrology, hydrogeology, limnology, engineering, and wetland ecology in Wisconsin. Over the course of a year, the group convened to discuss current climate-related water resources research, potential climate change impacts, possible adaptation strategies, and future research and monitoring needs. We also hosted several workshops to solicit ideas from other professionals, garnering additional information and ideas.

This report serves as the first assessment of the impacts of climate change on our water resources and outlines preliminary strategies to adapt to projected changes. As we gain a better understanding of the downscaled climate data specific to Wisconsin, future reports will further refine how we expect our water resources to change and how we can be proactive in preparing for those changes at statewide and local levels.

The goals of developing water resource adaptation strategies to climate change dovetail well with ongoing priorities and concepts that guide our water resource management programs in Wisconsin.

Climate change may compel managers to emphasize and prioritize these issues and perhaps will be used to leverage additional resources to implement the needed strategies. The goals are as follows:

- **Minimize threats to public health and safety by anticipating and managing for *extreme events*--floods and droughts**
  We cannot know when and where the next flooding event will occur or forecast drought conditions beyond a few months, but we do know that these extreme events may become more frequent in Wisconsin in the face of climate change. More effective planning and preparing for extreme events is an adaptation priority.

- **Increase resilience of aquatic ecosystems to buffer the impacts of future climate changes by restoring or simulating natural processes, ensuring adequate habitat availability and limiting human impacts on resources**
  A more extreme and variable climate (both temperature and precipitation) may mean a shift in how we manage aquatic ecosystems. We need to try to adapt to the changes rather than try to resist them. Examples include managing water levels to mimic pre-development conditions at dams and other water-level structures, limiting groundwater and surface water withdrawals, restoring or reconnecting floodplains and wetlands, and maintaining or providing migration corridors for fish and other aquatic organisms.

- **Stabilize future variations in water quantity and availability by managing water as an integrated resource, keeping water "local" and supporting sustainable and efficient water use** Many of our water management decisions are made under separate rules, statutory authorities, administrative frameworks, and even different government entities. This can lead to conflicting and inconsistent outcomes. In the face of climate change, the more we can do to integrate these decisions at the appropriate geographic scale, the better adapted and ready for change we will be. In addition, treating our water as a finite resource and knowing that supply will not always match demand will allow for more sustainable water use in the future.

- **Maintain, improve, or restore water quality under a changing climate regime by promoting actions to reduce nutrient and sediment loading** Water quality initiatives will need to be redoubled under a changing climate in order to minimize worse-case scenarios such as fish kills, harmful blue-green algae blooms, or mobilization of sediments and nutrients and to prevent exacerbation of existing problems.

Assumptions, Climate Drivers, and Uncertainties

We reviewed and incorporated into our assessment the WICCI Climate Working Group's projections for temperature, precipitation (including occurrence of events), and changes in snowfall in multiple locations in the state for 1980-2055. The WRWG used the following projections to guide our evaluation of potential impacts on hydrologic processes and resources.

- Thermal impacts will include increased air and water temperatures, longer ice-free periods, and more evaporation and transpiration.
- Changing rainfall patterns will include seasonal and spatial variability, less precipitation in the form of snow, and more water in some parts of the state but less in other parts.
- Storm intensities will increase, with slightly more frequent events of greater than two inches of precipitation in a 24-hour period.

Climate drivers are factors that may cause change or impact the resource. The main drivers we identified are *large rainfall events*, *water availability*, or *warming temperatures*.

- *Large rainfall events* are thought of as frequent rainstorms, rainstorms that are high in intensity, and rain that falls over a long duration and/or at times of the year when resources are most vulnerable to change.

- *Water availability* could be either positive (too much), such as flooding, or negative (too little), such as a drought. Too much or too little precipitation can affect water resources. These changes, as shown in the WICCI climate change maps, vary across the state. The seasonal variation in temperature will also affect the form of precipitation, particularly through less snow.

- *Increase in temperature* includes both air and water temperatures, longer ice-free periods in the winter, and an increase in evapotranspiration (ET).

Understanding the role of evapotranspiration and its affect on the water budget has been identified as one of our group's key research needs in climate projections. However, we are using the assumption of the Climate Change Working Group that ET will increase in most locations in the state because of warmer conditions, but how this will affect water resources is not clear. Increased ET may override increases in precipitation, negating potential changes in lake levels.

Historical Analysis

Our group recognizes the strong relationships between past trends in climate and hydrologic responses. Robust data sets of ice cover indicate that since the 1850s, average ice cover has decreased between 10 and 40 days, with greater effects in southern lakes, such as Lake Mendota, where the period of ice cover has declined 19 days per century (Magnuson et al., 2003).

Lake level responses are not spatially consistent statewide, according to limited U.S. Geological Survey data sets. In the north central part of the state, water levels of many lakes have gradually decreased and are currently at the lowest levels in the 70-year record. In the central part of the state, water levels have been variable and are currently low, but not as low as in the 1930s and 1960s. In the southern part of the state, water levels appear to have increased since the 1960s but parallel historic climate change statewide. Groundwater levels have responded similarly.

The WRWG also reviewed the recent Wisconsin DNR analyses of stream flow characteristics in Wisconsin streams for the period similar to the analysis window of Kucharik et al. (2010). The analysis revealed mean annual flow increasing overall statewide by about 14 percent over the past 56 years, which is consistent with Kucharik et al. (2010) and their reported 10-15 percent increase in precipitation over the same period (Figure 1). As with the lake level and groundwater monitoring wells, decreases in annual flow were observed only in north central Wisconsin.

Impacts of Climate Change

We expect that there will be systemwide changes in hydrologic patterns that may not be completely predictable. There may even be times when abrupt and long-term changes take place. Examples include groundwater flooding when groundwater tables may rise as much as 12 feet in one season, leaving formerly dry ground inundated for the foreseeable future or streams drying up due to lack of recharge.

Lakes

We believe that lakes will change because of climate change. Increased precipitation will increase sediment and nutrient loads from runoff, particularly when the surrounding land use is agricultural, developed, or undergoing development. When lakes become enriched with nutrients and sediments, their trophic status is likely to change over time and water quality may decrease. Flooding may allow water bodies to become interconnected, spreading invasive species from one lake to another. Flooding can also lead to shoreline erosion, increased property damage, and dam failures.

Changes in lake levels will be affected by increased precipitation and also by drought. Shallow lakes are most affected by lowered water levels, as are the littoral zones of deep lakes. Seepage lakes are the most sensitive to changes in precipitation and groundwater elevations. In some cases, a lake's chemistry can shift completely based on changes in its water source from primarily precipitation and overland flow to primarily groundwater. These changes are difficult to predict because of the cyclic nature of droughts. Further, the climate models are less clear about predicting future precipitation forecasts at this time.

River Base Flow Trends
and Precipitation Change 1950 - 2006

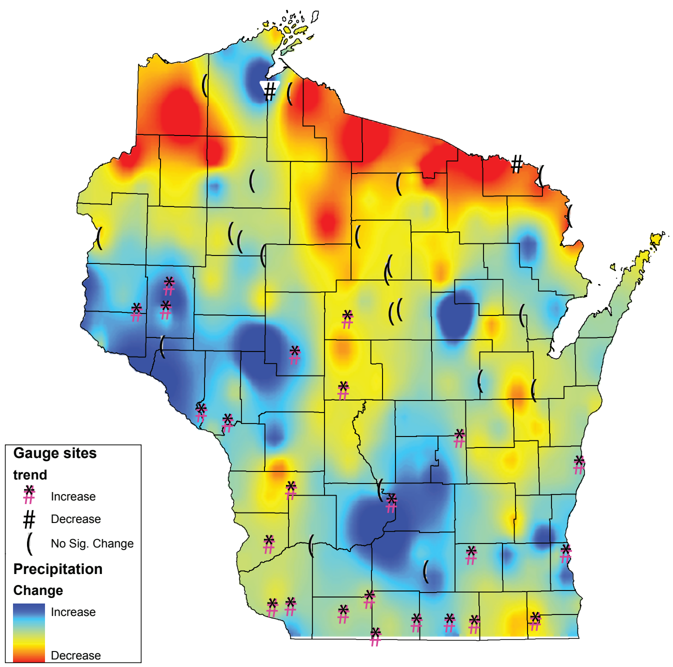

Figure 1. From 1950-2006, Wisconsin as a whole has become wetter, with an increase in annual precipitation of 3.1 inches. This observed increase in annual precipitation has occurred primarily in southern and western Wisconsin, while northern Wisconsin has experienced some drying. The southern and western regions of the state show increases in baseflow, corresponding to the areas with greatest precipitation increases. (Kucharik, 2010, and Greb, unpublished data; map prepared by Eric Erdmann, Wisconsin Department of Natural Resources, 2010.)

Increased temperatures will change the biological composition of a lake. Species native to warmer areas may survive in a future warmer Wisconsin. Species composition may shift from a predominance of green algae to blue-green algae. Coldwater fish species may shift north and be locally extirpated due to warmer water.

With increased temperatures, moderately shallow lakes may no longer stratify and instead continually mix. Internal phosphorus loading would then play a dominating force in a lake's dynamics and affect its trophic status. We may see the ice-free period last longer, and some lakes may not freeze at all.

Rivers and Streams

The state's thousands of miles of rivers and streams will also be affected by a changing climate. Historical records show increases in precipitation result in increases in river and stream baseflow and that decreases in precipitation lead to decreases in baseflow. We anticipate that the predicted increased precipitation will lead to increased baseflow. Increases in winter and spring precipitation will likely cause large runoff events, resulting in soil erosion, channel erosion, and increases in sediment and nutrient transport.

Changes in precipitation patterns will result in changes in the size and shape of stream channels. Channel-forming flows will occur more frequently, resulting in channel widening and down-cutting. These changes will reduce aquatic habitat and contribute additional sediment to our stream systems.

As is true with lakes, we expect that increases in temperatures will change fish species composition in our streams. Coolwater and coldwater fish species may no longer dominate some of Wisconsin's streams. Lower baseflow would also change trout habitat.

Groundwater

Climate change will affect groundwater resources across the state. However, given the diverse geologic and hydrogeologic conditions present within the state, the nature of the change will be site-specific, depending on soil and land cover characteristics, topography, depth to bedrock, depth to groundwater, and land use practices. Climate change will alter groundwater recharge. The most significant impacts will be on shallow groundwater systems rather than on deep groundwater systems, which are more resilient to change.

Changes in recharge can also cause dramatic changes in the dynamics of lake, stream, and wetland systems. Decreased recharge would result in reduced flow from springs, lower baseflow in streams, loss of some wetlands, and lower lake levels. An increase in the frequency of intense storms could recharge groundwater levels to the point of rising above the ground surface, causing groundwater flooding (Figure 2).

A rising water table will also decrease the distance between the land surface and groundwater, making the groundwater more susceptible to contamination.

Increased temperatures in Wisconsin, resulting in a longer growing season, could also place a greater demand on our groundwater resources to be used for irrigation.

Wetlands

Wetlands are also vulnerable to climate change. Changes in water levels will affect the range and extent of wetlands in the state. This includes conversions of wetland type and declines in wetland biodiversity due to the proliferation of invasive plants. Changes in wetland hydrology and plant composition will, in turn, alter some wetlands' ability to provide important functions such as flood storage, water quality improvement, shoreland protection, and breeding and foraging habitat for fish and wildlife.

Adaptation Strategies

Our working group used results from our meetings and workshops to determine what we believe are the highest priorities of climate change impacts on our water resources and to propose adaptation strategies. All of these physical, chemical, and biological impacts are anticipated to affect food webs and, ultimately, the status of Wisconsin's rich fisheries. In many cases, these impacts will call for policy changes.

Figure 2. Flooding in 2008 near Spring Green was caused by groundwater rising over the land surface.

This list represents the first consensus-based attempt to develop water resources responses to climate change in Wisconsin. Each impact listed below is followed by possible adaptation strategies.

Increased impacts of flooding on urban infrastructure and agricultural land, especially in low-lying areas and large watersheds.

- Identify, map, and prioritize potentially restorable wetlands (PRWs) in floodplain areas.
- Restore prior-converted wetlands in upland areas to provide storage and filtration and to mitigate storm flows and nutrient loading downstream.
- Develop both long-term and short-term changes in community infrastructure.

Increased frequency of harmful blue-green algal blooms due to nutrient rich runoff, lake stratification, and changes in water levels.

- Increase monitoring of inland beaches and develop better prediction tools for blue-green algal toxins.
- Develop statewide standards for blue-green algal toxins and take appropriate action.

Conflicting water-use concerns based on increased demand for groundwater extraction due to variable precipitation projections and warmer growing season temperatures.

- Relocate large water uses to areas with adequate and sustainable water sources, including large rivers or the Great Lakes.
- Encourage rural and urban water conservation through incentives and regulation.
- Promote integrated water management planning using long-term projections of supply and demand, tied to land use and economic growth forecasts.

Changes in seepage lake levels due to variable precipitation, recharge and increased ET. There are additional implications for water chemistry, habitat, and shorelines.

- Enhance and restore shoreline habitat (coarse wood, littoral and riparian vegetation, bio-engineered erosion control) to withstand variations in water levels.
- In areas with lower lake levels, enhance infiltration by reducing impervious surfaces in urban/riparian areas and changing land management practices.
- Change planning and zoning for lakeshore development to account for changes in water levels.
- Adjust and modify expectations and uses of lakes, especially seepage lakes; recognize that some lakes are not suited for all uses.

Increased sediment and nutrient loading to surface waters during earlier and more intense spring runoff events.

- Resize manure storage facilities, wastewater facilities, stormwater drains, and infrastructure to accommodate increased storm flows to protect water quality.
- Reverse the loss of wetlands; restore prior-converted wetlands to provide storage and filtration by mitigating storm flows and nutrient loading.
- Protect recharge/infiltration areas and riparian buffers.
- Incorporate water management strategies based on climate projections into farm-based nutrient management plans.

Increased spread of aquatic invasive species due to changes in hydrology, water temperatures, and warmer winter conditions.

- We did not develop adaptation strategies for this impact for this report. Since this is a first draft *working* document, we know that additional adaptation strategies will be developed, evaluated, and refined over the coming years, including a strategy for aquatic invasive species.

Future Recommendations

This report serves as the first assessment of the impacts of climate change on our water resources. The mission of the working group is broad and is expected to continually develop in the future. We anticipate that future reports will help further refine identification of impacts of climate change on water resources as well as adaptation strategies.

The WRWG recommends that detailed hydrologic budgets and models be developed at appropriate local scales (watersheds, aquifers) in order to develop suitable adaptation and management strategies. The complexity of the state's surface and subsurface geology, soils, land use, and land cover patterns necessitates the need for appropriate downscaling.

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WILDLIFE WORKING GROUP

Wisconsin is world-renowned for its diversity of ecological landscapes and wildlife populations. The northern forests, southern prairies, and interior and coastal wetlands of the state are home to more than 500 terrestrial animal species. These animals supply our state with aesthetic, cultural, and economic benefits; our identity and economy are intertwined with these natural resources. Climate change is altering the behavior, distribution, development, reproduction, and survival of these animal populations. In turn, these changes will alter the aesthetic, cultural, and economic benefits we receive from them. The focus of the Wildlife Working Group is to document past and current impacts, anticipate changes in wildlife distribution and abundance, and develop adaptation strategies to maintain the vitality and diversity of Wisconsin's wildlife populations.

Impacts

For animals, the impacts of climate change may be direct or indirect, or more commonly both:

Direct Impacts

For those with a direct life-history linkage to temperature, precipitation, and other ambient conditions, direct impacts of climate change are of most concern. With changes in climate patterns, some wildlife populations are experiencing weather-climate conditions for which

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they are no longer suited. There is a common set of direct climate impacts that will alter the behavior, distribution, development, reproduction, and/or survival of many animal populations:

- Advance of spring conditions – affecting migration, breeding, and life-cycle timing (phenology).
- Spatial shift in suitable climate conditions – affecting the distribution of a species on the landscape.
- High-temperature events – causing physiological stress or death.
- Altered snow cover – increasing exposure to cold and/or changing food availability.
- Drought – causing physiological stress or death.
- Heavy precipitation/flooding events – destroying habitat or injuring and killing wildlife.

Indirect Impacts

The indirect impacts of climate change on wildlife are equally important to consider:

- Changes in habitat: The distribution and abundance of animal species are largely defined by the type, amount, and quality of suitable vegetation. The response of vegetation to climate change may be rapid and how this will affect animal populations is a major concern.
- Species interactions: Climate change will alter how species interact with each other. This may break, intensify, or establish novel relationships between species with consequences for ecosystems and society.

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Non-climate Stressors

It is important to note that climate change is not the sole threat to wildlife populations. Currently, habitat loss or degradation, invasive or non-native species, and pollution threaten the conservation of Wisconsin's wildlife. Often, these threats act in concert to hasten the decline of wildlife populations. In many instances, the threats act synergistically; the presence of one threat intensifies and amplifies the other. Climate change is not only an additional threat to wildlife populations but also acts synergistically with existing threats to the detriment of wildlife populations. Multiple threats, acting in concert, are of great concern to natural resource managers.

Loss of Biodiversity

Climate change will not have adverse impacts on all wildlife. Although there will likely be more "losers" than "winners," some species will fare well under future climate conditions. More losers than winners will result in a simplification of our landscape and wildlife. Population increases from our most common species (for example, European starlings, Canada geese, and gray squirrels) will come at the cost of our most vulnerable (for example, purple martins, black terns, and American martens). This will result in a net loss of biodiversity and a biological simplification of our ecological communities. For society, the negative consequences of this simplification are aesthetic, cultural, and economic. Until we can wholly estimate the impacts of biodiversity loss, it is most prudent to heed the advice of Aldo Leopold, Wisconsin's great wildlife ecologist: "to keep every cog and wheel is the first rule of intelligent tinkering."

Assessing Impacts

As wildlife ecologists and managers in the state, we are interested in the potential impacts of climate change on all wildlife species. Given the complexity of climate change impacts and our limited knowledge of some species, a detailed assessment for all species is not feasible at this time. For this reason, we are conducting a two-part assessment process: 1) screening of 463 species for sensitivity to climate change and its associated impacts and 2) detailed conceptual modeling for a subset of species that serve critical roles in ecosystems and society. The species selected for our case studies fall into one or more of the following categories:

- Keystone species, which exert large impacts on the ecosystem.
- Rare species, or those of conservation concern.
- Economically important species that are harvested or provide important ecosystem services.

In this report, we highlight the potential impacts of climate change on nine species in the state: American marten, eastern red-backed salamander, white-tailed deer, black tern, common loon, wood frog, greater prairie chicken, Karner blue butterfly, and bullsnake. These case studies illustrate not only the direct and indirect impacts of climate change on these populations but how climate change will exacerbate existing stressors on the populations.

Adaptation Strategies

Climate change introduces new and unparalleled challenges to wildlife and land managers, namely, great uncertainty about future conditions. Furthermore, our understanding of the indirect effects of climate change is limited. The development of species-specific adaptation strategies requires a detailed understanding of the direct and indirect impacts of climate change and other stressors on the distribution and abundance of a population. It also requires some understanding of the relative benefits of multiple management options. Because this assessment process is in its infancy, we do not yet have detailed, species-specific recommendations. In lieu of such recommendations, we review broad wildlife and land management principles demonstrated to be beneficial to wildlife health and diversity.

- ***Land protection*** is of increasing importance, but given financial constraints, it should be grounded in climate-sound strategies such as representing multiple habitat types or populations of a species across a reserve system, ensuring connectivity among protected areas, and considering keystone species in reserve systems.

- Good stewardship of ***wildlife habitat management*** will continue to be important, and we should integrate a suite of principles into this process:
  - practicing adaptive management
  - reducing existing threats
  - re-creating natural disturbance processes
  - building public-private partnerships
  - expanding education-outreach

Research and Monitoring

Assessing the risks to Wisconsin's wildlife from climate change and generating effective climate change adaptation strategies is an incredibly complex task. Toward either goal, we must adopt an adaptive management strategy that integrates high-quality science with comprehensive, interagency planning and implementation efforts. As our scientific understanding increases over time, we will work with other scientists, policy-makers, and natural resource managers to incorporate this new knowledge into planning and implementation efforts.

Photo: Kevin Kenow

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