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.

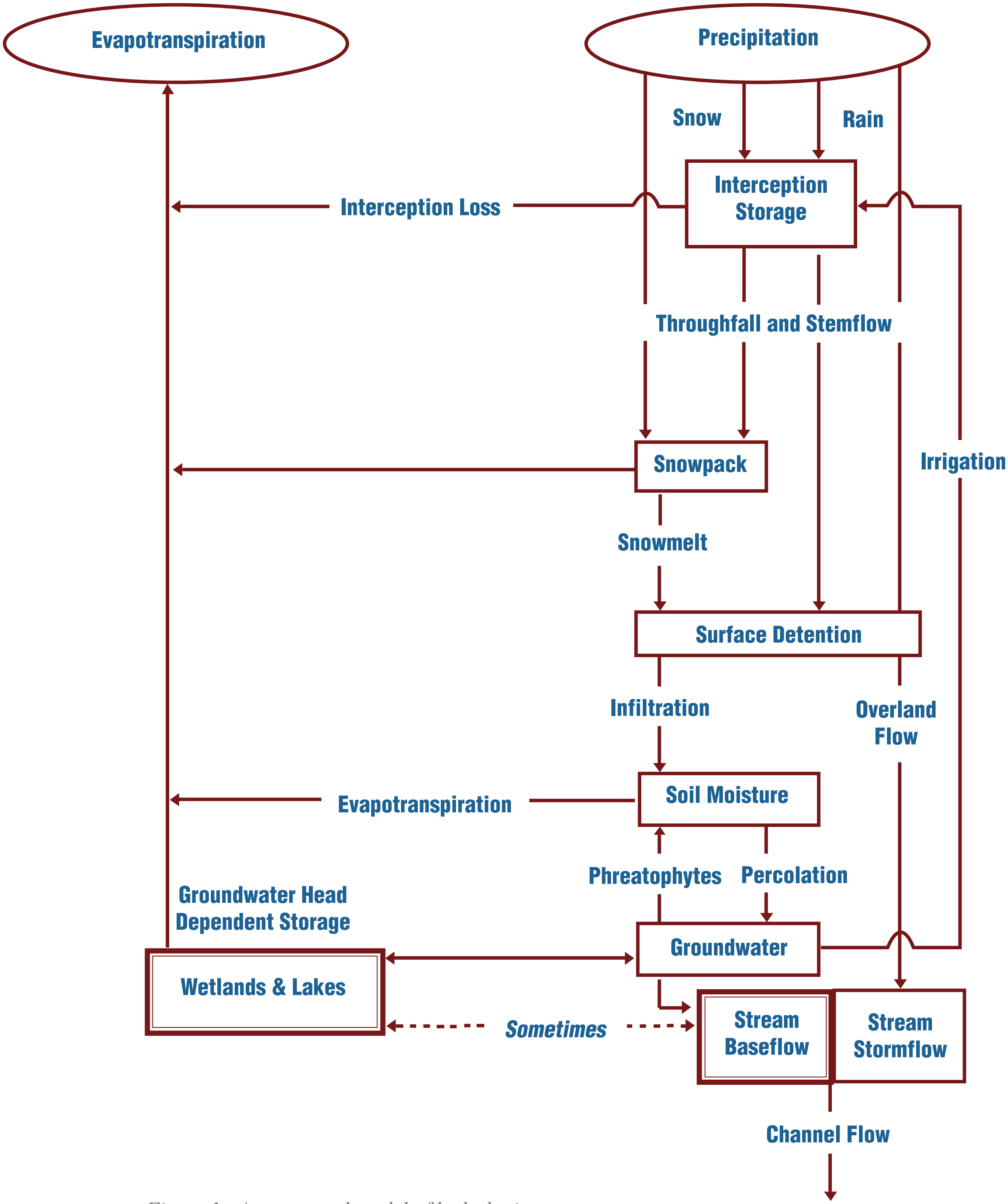

Figure 1. A conceptual model of hydrologic processes.

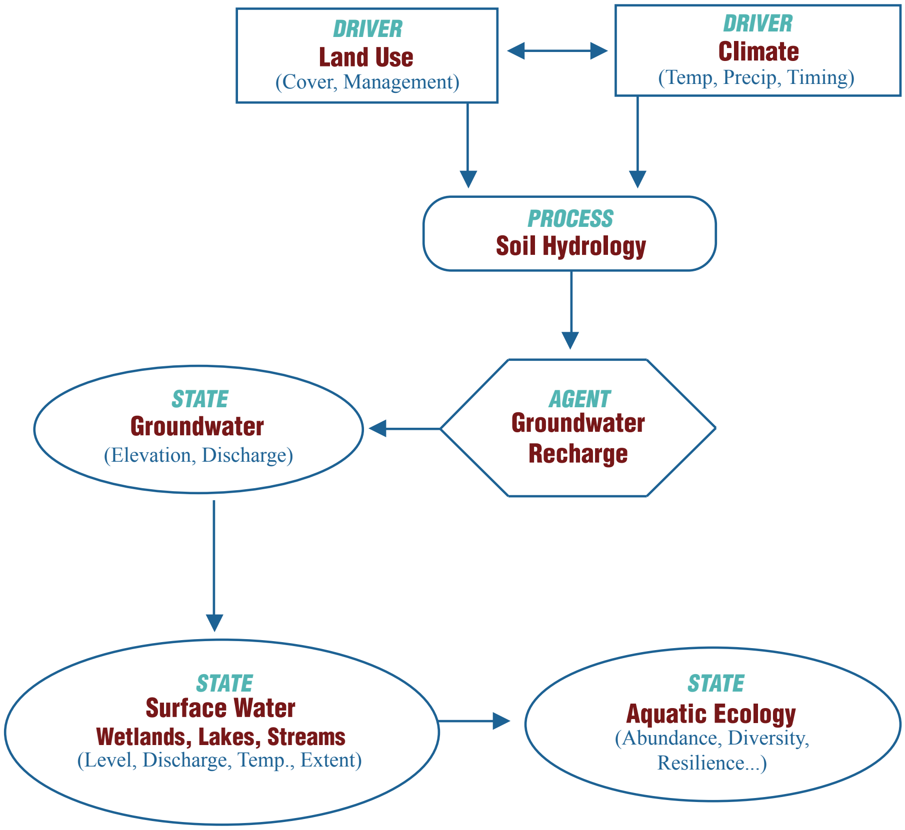

Figure 2. A conceptual model of evolving land cover and management.

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-

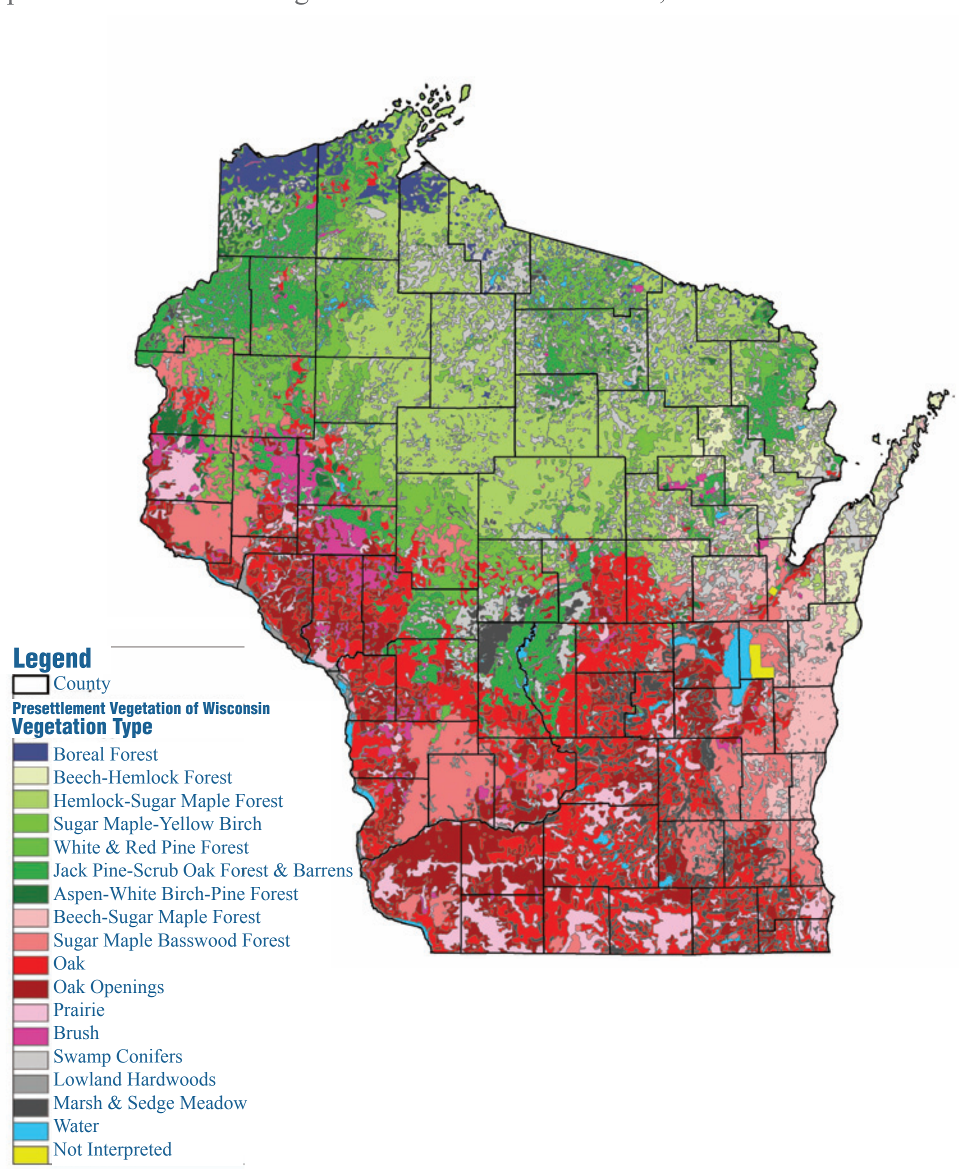

Figure 1. Early vegetation of Wisconsin.

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.

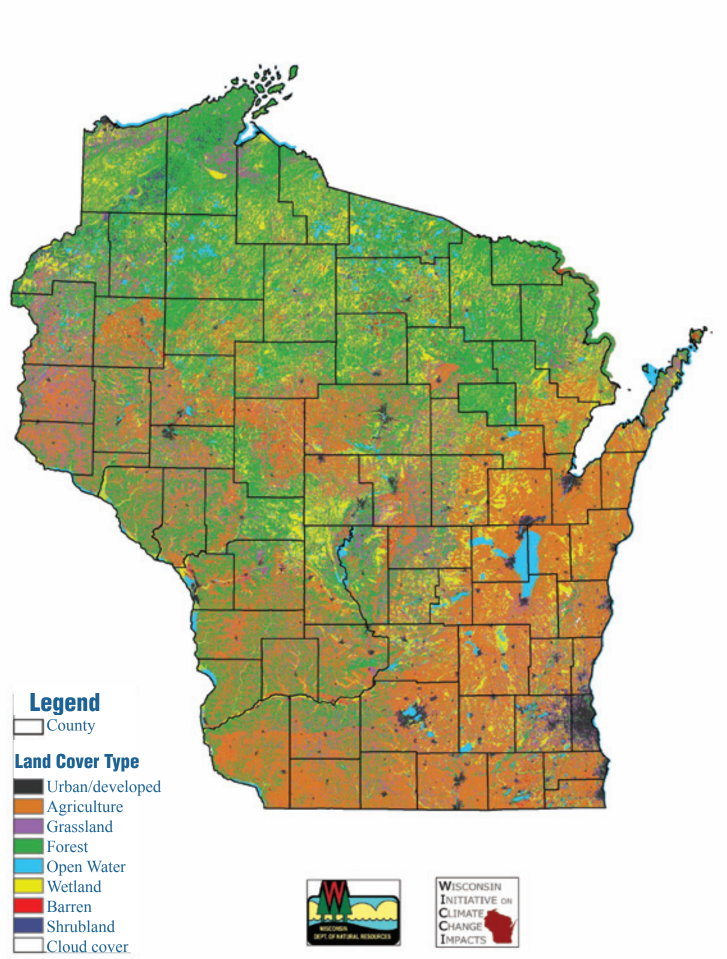

Figure 2. Land cover in Wisconsin.

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.

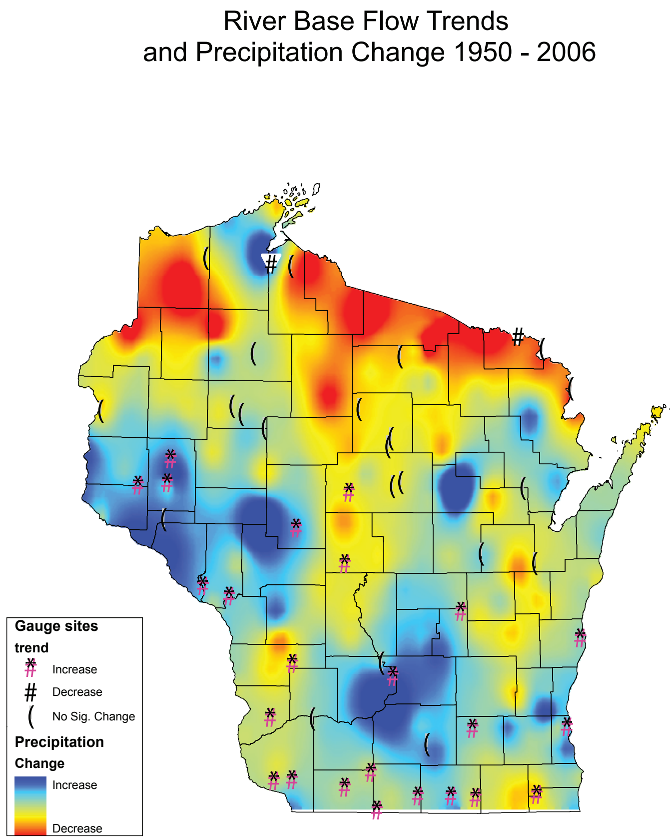

Figure 1. From 1950-2006, Wisconsin as a whole has become wetter, with an increase in annual precipitation of 3.1 inches. This observed increase in annual precipitation has occurred primarily in southern and western Wisconsin, while northern Wisconsin has experienced some drying. The southern and western 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.

References

Greb, S.R. (unpublished data). Historic Trends in Flows of Wisconsin's Rivers and Streams. Wisconsin Department of Natural Resources.

Kucharik, C. J., Serbin, S. P., Vavrus, S., Hopkins, E. J., & Motew, M. M. (2010). Patterns of climate change across Wisconsin from 1950 to 2006. *Physical Geography*, 31(1).

Magnuson, J. J., Krohelski, J. T., Kunkel, K. E., & Robertson, D. M. (2003). Wisconsin's water and climate: Historical changes and possible futures. In C. Meine (Ed.), *Wisconsin's Waters: A Confluence of Perspectives* (pp. 23-36). Madison, WI: Wisconsin Academy of Sciences, Arts & Letters.

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