Climate Change and Renewable Energy:

Management Foundations

August 2011

Version 1.03

Minnesota Department of Natural Resources
Climate and Renewable Energy Steering Team

A Primer for DNR Staff

This document provides a platform for DNR staff to discuss and build management strategies to address climate and renewable energy challenges. The report describes the current science on climate and renewable energy issues and provides a common framework for exploring management responses.

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Credits

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Acknowledgements

Climate Change and Renewable Energy: Management Foundations is the result of the hard work of many natural resource professionals and scientists. The Climate and Renewable Energy Steering team would like to acknowledge and offer sincere thanks for their contributions to this report. Below we list individuals who reviewed sections of this report or made other important contributions. Thank You.

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Commissioner's Office Message

Minnesota's climate is changing. Global energy demands are impacting both how the DNR operates and the natural resources we protect. We know this. And with this report from our newly formed Climate and Renewable Energy Steering Team (CREST), we are launching our agency's most comprehensive effort yet to do something about it.

Climate change and shifting energy use toward local and renewable sources represent one of the most complex set of challenges we've ever faced as an agency. They will require our best innovation and creativity. The DNR has both a duty, and a mandate, to act.

Our duty comes from our mission to act as stewards of Minnesota's natural resources. We have a responsibility to prevent and mitigate the risk of damage to our woods, waters, prairies, and wildlife. While there is still considerable social and political debate about climate change and its causes, we should not be afraid to talk about climate change. The best science tells us that the risks are no longer a distant challenge, they have become immediate. Just look at northern Minnesota, where average annual temperature have increased by more than 2° F over the past century.

Our mandate comes from legislation and the Governor himself. Minnesota's Next Generation Energy Act of 2007 requires the state to reduce fossil fuel use by 15% by 2015 and increase renewable energy to 25% of total energy use by 2025. On April 8, 2011, Governor Mark Dayton signed two executive orders mandating all state agencies to be leaders in energy conservation and renewable energy practices that reduce the climate impacts from greenhouse gas emissions.

The natural lands that we manage play a unique role in mitigating climate change. A recent national study finds that America's forests, grasslands, and wetlands absorb 40% of the greenhouse gas emissions released into the air. Minnesota's natural lands do this while also providing clean water, forest products, wildlife habitat, and recreation. However, climate change is altering Minnesota's natural lands and the uses they sustain. This report documents existing and predicted impacts in Minnesota, ranging from declining coldwater fish species and shifting tree species ranges to declining seasonal ice cover and reduced winter logging time. These impacts will threaten the ability of DNR and our partners to achieve our common conservation goals. For example, restoring duck populations becomes more difficult if projected climate change results in fewer wetlands throughout the prairie pothole region.

To meet the challenges posed by these trends, we chartered the Climate and Renewable Energy Steering Team (CREST) and its five work teams to provide agency-wide coordination and guidance on climate change and renewable energy strategies. CREST produced this *Management Foundations* report to define what we know as an agency about climate and energy trends, and to provide a framework for protecting Minnesota's natural resources.

The good news is, we have already demonstrated leadership and success in this arena. Newly constructed state parks buildings are models of energy efficiency and sustainable design. Wildlife Management Areas are producing grass and woody biomass sources that will help create sustainable biofuel markets in Minnesota. DNR ecologists and biologists are conducting cutting-edge research to understand how species such as moose and cisco are responding to climate change. We must now bring this kind of leadership to all work throughout the agency as we improve the resilience of our natural resources in the face of a shifting climate and we further reduce our own carbon footprint by using less energy and consuming fewer materials.

This report is an important step in launching this agency-wide effort. Please review this report carefully, discuss with your peers, and provide feedback to the CREST team. CREST needs your input to develop further strategies for implementing climate change and renewable energy strategies. As you read the report, you'll quickly realize how daunting this challenge is. But our history is one of meeting challenges before they become a crisis. There are many examples: the recovery of deer, wild turkey, and trumpeter swan populations; the development of the premier state park, state trail, and state wildlife area systems in the country; certification of state forest lands; development of a managed system of state motorized trails; recovery of the Red Lake fisheries; and the list goes on. Many of these accomplishments seem easier than dealing with global forces in climate and energy that threaten to undo much of what we've accomplished in conservation over the past century. But the point is, the DNR has been the source of innovative and creative solutions before. We can, and must, do so again. I know about the talent within this agency and I'm convinced we can succeed.

Thank you for the work you do to strengthen our ability to adapt to changing times and succeed in meeting our conservation mission.

Dave Schad
DNR Deputy Commissioner
August 2011

About this Report

Purpose

Climate Change and Renewable Energy: Management Foundations provides a platform for DNR staff to discuss and build management strategies that address climate change and renewable energy challenges.

With accelerating climate change, DNR will need to evaluate its most basic management work. We will need to incorporate future climatic conditions into our decisions. Are we managing public lands in ways that improve their resilience to a changing climate? Are we planting the right tree species in the right places? Are we protecting the right lands in the right places and connecting habitat in climate-smart ways? DNR will base these and other management decisions on the best available science and adapt its actions as new information is developed.

The report serves as a bridge between the broad climate change and renewable energy strategies identified in DNR's Strategic Conservation Agenda and more specific actions DNR must take to mitigate climate change and adapt to its effects.

The report:

- provides common definitions for explaining climate and renewable energy concepts,
- summarizes the science on climate and energy trends, impacts, and responses,
- outlines DNR's current work responding to climate and renewable energy challenges, and
- describes a framework for integrating and improving climate change and renewable energy strategies as we learn more.

This report is a foundational first step. It is DNR's first coordinated assessment of the risks and opportunities associated with a changing climate and a growing demand for new energy sources. Future reports, fact sheets, and training workshops will provide more operational guidance applicable to specific habitats, resources, and energy challenges. DNR will track performance of climate change and renewable energy strategies by identifying measurable indicators and targets in its Conservation Agenda: Performance and Accountability Reports.

Audience

This report is primarily intended for DNR employees. It provides integrated information on climate science and management options needed to inform decision making. DNR staff representing all agency disciplines contributed to, reviewed, and revised this report. DNR commissioners approved the report in June 2011.

The Climate Change and Renewable Energy Steering Team (CREST)

This foundations document is a product of DNR's Climate Change and Renewable Energy Steering Team (CREST). This team, established by DNR's Senior Managers and Operations Managers teams in 2010, provides department-wide coordination and guidance on climate change and renewable energy strategies. Four interdisciplinary work teams support CREST including the: Climate Change Adaptation Team, Carbon Sequestration Team, Biofuels Team, and Energy Efficiency Team. An Integration Team ensures coordination across the work teams. These and related department teams promote tools that help make Minnesota's natural lands and waters more resilient to climate change and help reduce DNR's carbon footprint. High priority, immediate-term work tasks are listed in Box 1.

BOX 1. DNR Climate Change and Renewable Energy Priorities FY 2012

The Climate and Renewable Energy Steering Team (CREST), its five work groups, and related department teams have set priority tasks for FY 2012. A summary of the tasks follows:

Climate Change Adaptation

- Conduct "vulnerability assessments" that identify species and habitats most vulnerable to climate change.
- Recommend adaptation strategies for major ecosystems (e.g., forests, wetlands).
- Disseminate results of department-wide climate change survey and recommend targeted training and education efforts for staff.

Biofuels

- Complete GIS analysis of constraints affecting woody biomass availability.
- Finalize and distribute biomass harvest guidance document and engage staff in addressing biomass harvesting issues.
- Document lessons learned from biofuels demonstration projects.

Energy Efficiency

- Launch Site Sustainability Team pilot projects to identify and implement site-specific energy and sustainability improvements.
- Complete pilot of technology for trip planning and vehicle sharing to reduce fuel consumption.
- Increase number of available sustainable product options and train buyers on green purchasing policy.

Carbon Sequestration

- Develop tools for measuring and managing carbon in Minnesota's ecosystems.
- Participate and influence forest carbon accounting protocol development.
- Conduct pilot projects that will test carbon sequestration strategies and accounting protocols.

Integration Functions

- Develop and implement a climate and renewable energy communications plan focused on internal communications.
- Disseminate this report widely throughout the department; convene discussions to share report findings and determine next steps.
- Promote and enhance partnerships with other agencies, universities, and private groups working on climate change and renewable energy issues.

Priorities and tasks will evolve over time. For the most current information on team activities, please visit the CREST intranet site: http://intranet.dnr.state.mn.us/workgroups/crest/index.html.

Executive Summary

Part I: Climate and Energy Trends and Impacts

Minnesota Climate Trends and Projections

Climate change is occurring in Minnesota. (p. 14)

- Minnesota's average annual temperature has increased by 1.9° F. since 1895.
- Warming rates are accelerating, especially in winter.
- Annual precipitation in Minnesota has increased by about 3.1" since 1895 (2.7" per century).

The magnitude of climate change in Minnesota is predicted to increase over the next century (p. 18).

- Average annual temperatures are projected to increase by 5–9° F. by the end of the century.
- Average annual precipitation is projected to increase by 6.8–11.5% by the end of the century.
- Average summer precipitation is projected to remain at levels similar to those seen today. Combined with temperature increases, this would cause a net drying effect in soils and water levels during much of the growing season.
- By the year 2069, various landscape regions in Minnesota are projected to experience climates that today are found much farther south (for example, Minnesota's north-central lakes region would have a climate similar to northwestern Iowa, p. 19).

The science of climate-change prediction is rapidly developing, but many uncertainties remain. In general, precipitation projections are more uncertain than temperature projections.

Global Climate and Energy Context

Global energy trends are driving Minnesota's energy policy and choices (p. 20). Prices for energy (primarily oil and other fossil fuels) are expected to increase due to global demand and diminishing supplies. Renewable energy sources are expected to increase dramatically relative to their current levels. Many countries and states have enacted renewable energy standards. Minnesota's Next Generation Energy Act of 2007 mandates that 25% of the state's power come from renewable sources and that greenhouse gas emissions be reduced by 80% by 2025 based on 2005 levels.

Global temperatures have increased steadily over the past century (p. 20). Globally, 2010 was tied with 2005 for warmest year on record. In the 2000s, every year was warmer than the 1990s average. In the 1990s, every year was warmer than the 1980s average.

Climate Change Impacts on Minnesota's Natural Resources

Strong evidence suggests that recent global climate changes are increasing growing seasons, shifting the ranges of plant and wildlife species, and increasing the occurrence of fires, insect pests, disease pathogens, and invasive weed species (p. 24).

Three major biomes meet in Minnesota: tallgrass prairie, eastern broadleaf forest, and mixed coniferous forest (Fig. E-1). Transition zones between biomes are known to be particularly sensitive to climate change (e.g., biome boundaries can shift). These shifts can have dramatic effects on Minnesota's natural resources. Examples of "early signs of change" are listed in Box 2.

On Minnesota's more than 11,000 lakes and 65,000 miles of rivers and streams, likely climate-induced impacts include earlier ice-out dates, less seasonal ice cover, expansion of warmwater fish species in northern Minnesota lakes, increased growth of algae and diatom blooms, declining populations of coldwater fish species like ciscoes, warmer surface water temperatures in lakes, and increased flows in Minnesota streams (p. 22–23).

In wetlands, climate change threatens to alter physical, chemical, and biological processes (p. 32). Under projected warming scenarios, Prairie Pothole wetlands could shrink and shift optimal waterfowl breeding conditions into western Minnesota. Without major restoration efforts to replace drained wetlands in Minnesota, the prairie pothole "duck factory" could largely disappear by the end of the century (p.30–31).

Box 2. Early Signs of Change—A Few Examples

The following observations are "early signs" of climate change impacts in Minnesota. More details, references, and information on future projections and associated uncertainties are provided in the main body of the report.

Aquatic Systems

- Between 1973 and 2008, maximum seasonal ice cover on the Great Lakes declined by about 30%.
- Ice is breaking up earlier and forming later in Minnesota lakes. Ice-in dates shifted later by 7.5 days per decade between 1979–2002.
- Warmwater fish, notably largemouth bass and bluegill, are becoming more common in northern Minnesota lakes.
- Since 1975, a coldwater fish called cisco has declined in Minnesota by 42%. Recent evidence suggests that declines are primarily due to climate change. Cisco are an important food source for walleye, pike, and lake trout.
- Between 1953 and 2002, 69% of 36 stream gauging stations in Minnesota showed increases in mean annual flow (a 98% increase for stations with increases).

Forest, Wetland, and Prairie Systems

- Eleven northern tree species such as quaking aspen, paper birch, and sugar maple appear to be migrating north (through seed dispersal) at rates approaching 6 miles per decade.
- Shorter winters are reducing available time for winter logging, stressing an already troubled forest products industry in northern Minnesota.
- Over the past 10 years, the eastern larch beetle has killed tamarack trees on over 100,000 acres in Minnesota. Increased mortality may be partially explained by warming winter temperatures, which allow a greater proportion of eastern larch beetle adults to survive the winter.
- Winter ranges for ring-necked ducks, red-breasted mergansers, American black ducks, and green-winged teal all moved more than 150 miles north over the last 40 years.
- Eighteen out of twenty migratory bird species in the northern prairie region are migrating earlier in the spring.

Peatlands, which are currently important carbon sinks, may begin to dry out, causing them to add to carbon emissions into the atmosphere (p. 34).

For Minnesota's 16.7 million acres of forests, projected climate changes will shift tree ranges, and some common northern tree species such as spruce and fir may become rare in Minnesota (p. 37). Depending on whether precipitation rates increase or decrease, Minnesota's forests could either transition to communities dominated by central hardwood trees such as oaks and hickories, or forests could shrink and be replaced by grasslands (p. 37). In both scenarios, climate change will likely exacerbate and intensify the effects of invasive plant species, insect pests, and tree diseases (p. 38).

Minnesota's remnant prairies (less than 1% of pre-settlement prairie acreage) will likely become drier, causing declines in mesic and wet prairie plant and wildlife species (p. 41). The proliferation of invasive species will make it difficult for Minnesota's prairies to expand and take advantage of potential new habitat conditions created by a warming climate. Intensive human management, such as prescribed burns and seeding, will be necessary to facilitate new native prairie establishment (p. 41).

Part II: Management Response

Adaptation and Mitigation Strategies

DNR's management response to climate change pursues two core strategies: adaptation (helping humans and natural systems prepare for and adjust to climate change) and mitigation (reducing or removing greenhouse gases from the atmosphere).

Climate change adaptation strategies help human and natural systems prepare for and adjust to climate change. Examples include increasing species and genetic diversity in tree plantings to increase adaptability to future changes, increasing habitat connectivity to allow species to migrate as the climate changes, or increasing the diameter of culverts to deal with increased precipitation and runoff (p. 44).

Climate change mitigation strategies will focus in three primary areas: maintaining or increasing the carbon sequestration capabilities of natural lands such as forests, peatlands, and grasslands (p. 52); producing biomass to contribute to renewable energy goals while increasing conservation benefits such as reducing woody invasive species (p. 54); and, reducing DNR's total energy use by 20 percent from 2010 to 2015 (p. 57).

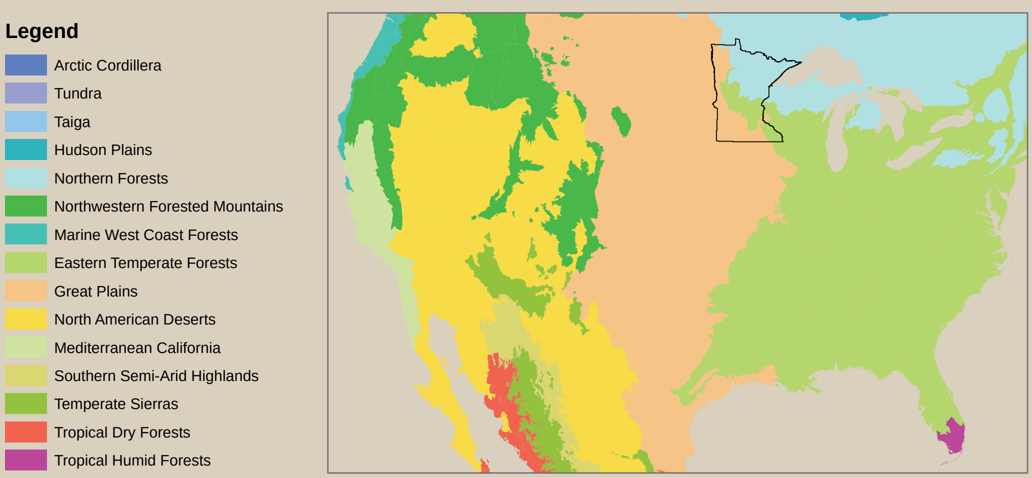


Fig. E-1. Three major biomes converge in Minnesota: Northern Forests, Eastern Temperate Forests, and the Great Plains. Biome transition zones are known to be particularly sensitive to climate change. Map Source: Commission for Environmental Cooperation (www.cec.org/naatlas).

A Framework for Decision Making

To help ensure effective, climate-savvy management decisions, DNR will use an adaptive management framework that links management response (adaptation and mitigation strategies) with assessments, planning and decision support, and monitoring. An adaptive framework is needed because of the uncertainties involved in predicting climate change and resulting impacts on natural resources. The framework will allow DNR to take action now, while adjusting and improving strategies as more information is gained.

Assessments in three areas are needed to understand climate and renewable energy issues and to prioritize adaptation and mitigation strategies. Vulnerability assessments will identify species and habitats that are most susceptible and unable to cope with the adverse effects of climate change (p. 60). Mitigation assessments will analyze opportunities for increasing carbon sequestration on natural lands and reducing DNR's energy use (p. 61). Social assessments will explore opportunities for stakeholder involvement and help identify information and training needs (p. 62).

Planning and Decision Support will organize the information and expertise gained from assessments and other sources in order to provide training, departmental guidance, decision support tools, and planning assistance—with the overall goal of providing the best ecological, economic, and social benefits possible in the face of climate change (p. 65).

Monitoring will collect and organize data on trends in climate and energy use, climate impacts on natural resources, and effectiveness of management actions aimed at addressing those impacts. Results from monitoring feed back into future assessments and management decisions so course corrections can be made if conditions change or if management actions are not effective (p. 66).

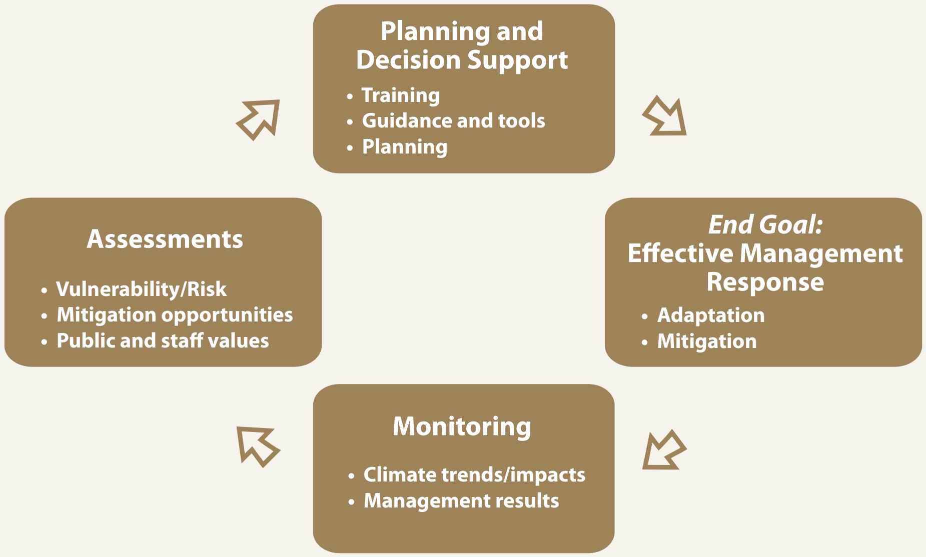


Fig. E-2. DNR's Climate Change and Renewable Energy Decision Framework aims to improve management decisions over time as we learn more.

BOX 3. Key Definitions

The following definitions provide a common language for defining climate and renewable energy issues and concepts. Additional definitions are available in the glossary.

Climate Change Adaptation

Actions that help human and natural systems prepare for and adjust to climate change.

Examples include increasing species and genetic diversity in tree plantings to increase adaptability to future changes, increasing habitat connectivity to allow species to migrate as the climate changes, or increasing the diameter of culverts to deal with increased precipitation and runoff.

Climate Change Mitigation

Actions that reduce greenhouse gas emissions or remove them from the atmosphere.

Examples include reducing energy consumption, switching to renewable fuels, or increasing acreage and volume of forests to increase carbon sequestration.

Carbon Sequestration

Biological carbon sequestration is a natural process—driven by photosynthesis—that removes carbon dioxide from the atmosphere and stores it in plants or soils.

A recent study found that America's forests, grasslands, and other terrestrial ecosystems can absorb up to 40% of the country's carbon emissions from fossil fuels. Minnesota's natural lands are unique in their ability to absorb greenhouse gas emissions while simultaneously providing a wide array of benefits including clean water, wildlife, recreation and forest products.

Climate Change Vulnerability

The degree to which an ecosystem, resource or species is susceptible to and unable to cope with adverse effects of climate change.

Vulnerability assessments will help to prioritize adaptation and mitigation policies, planning, and management efforts.

Weather and Climate

- **Weather** is what happens in a specific place at a specific time. On a given day, the weather may be rainy, or windy, or cloudy, or cold. Weather is described with specific numbers, such as temperature, atmospheric pressure, wind speed, and relative humidity.
- **Climate** is the character of the weather based on many observations over many years (typically 30 years or more). The numbers used to describe climate are likely to be ranges or averages rather than "here and now" quantities. Because climate is a long-term phenomena, it is impossible to draw conclusions about climate change from any single weather event. Climate change can only be observed by examining long-term data sets (Adapted from Minnesota DNR 2010c).

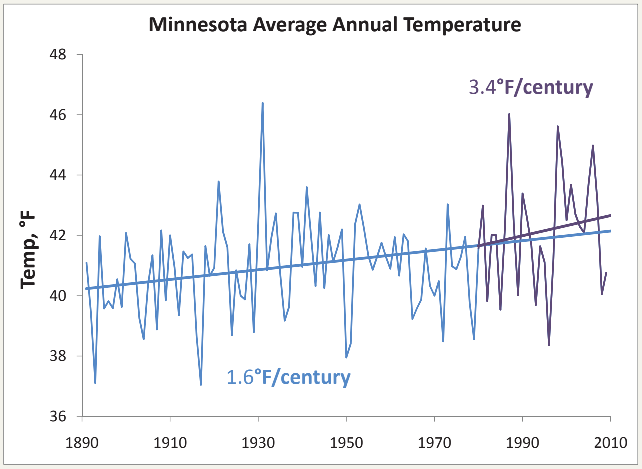
Part I: Climate and Energy Trends and Impacts

Minnesota Climate Trends and Projections

Temperature

From 1895 to 2009, Minnesota's average annual temperature increased by 1.9°F, (equivalent to a rate of 1.6°F per century; Fig. 1a). When only considering the years since 1980, the rate of increase is 3.4°F per century. This shows not only an increase in average temperature, but also an accelerating warming rate.

Minimum temperatures (daily lows) have increased at an even faster rate than average temperatures. Average annual lows increased by 2.5°F since 1895 (or a 2.1°F per century warming rate), and the warming rate increased to 5.7°F per century during the 1981–2009 period. The greatest warming rate occurred in winter lows (Fig. 1b: 3.5°F per century for 1895–2009; 8.1°F per century for 1980–2009), and the warming rates for minimum temperatures were greater than for average temperatures in all seasons. Warming rates have been higher in northern than in southern Minnesota (Fig. 1-2), a pattern consistent throughout the northern hemisphere (greater warming rates at higher latitudes; Trenberth et al. 2007).



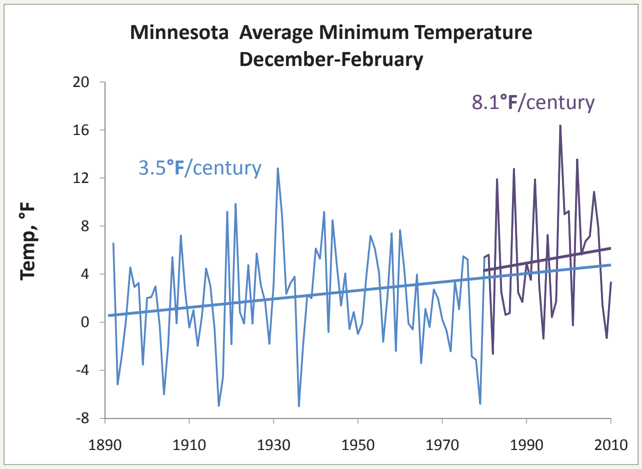


Fig. 1-1a and 1-1b. Increase in average annual (a) and winter minimum temperature (b) in Minnesota, 1895–2009. Blue lines and change rates are for 1895–2009; purple lines and change rates are for 1980–2009. Source: Minnesota State Climatology Office.

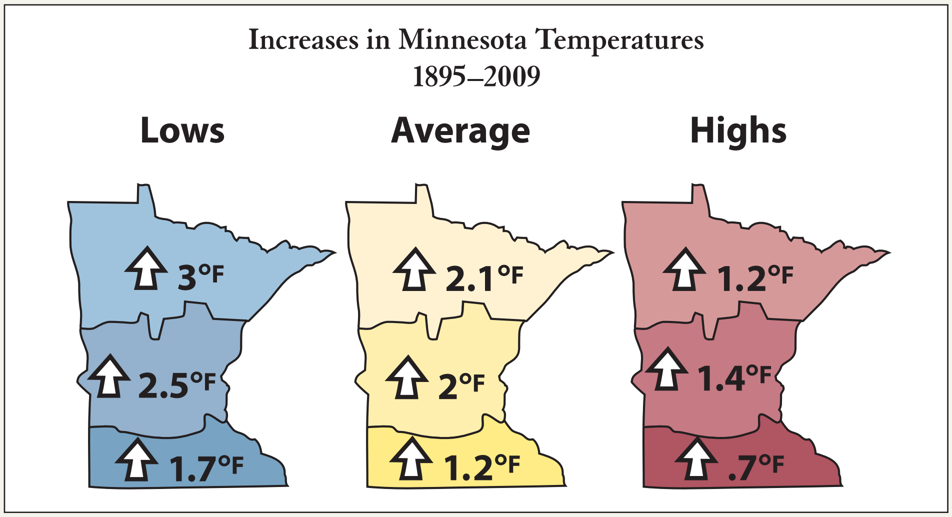


Fig. 1-2 Increase in year-round daily Lows, Highs, and Average Temperatures in Minnesota, 1895–2009 (Source: Minnesota State Climatology Office).

Lake Superior Water Temperature

Increased air temperatures lead to increased water temperatures. Long-term water temperature data are not available across the state, but temperature monitoring buoys have been deployed in Lake Superior since 1981 (source for figure: National Data Buoy Center). Figure 1-3 shows the results from one buoy near the center of Lake Superior: Surface water warmed 2.7°F. since 1981, or about 9.0°F per century. That warming rate is greater than those found in air temperatures in adjacent Minnesota land areas. In 2006 and 2010 the water temperatures at this buoy rose to summertime temperatures three to four weeks earlier than average. Longer periods of warmer surface waters generally produce higher evaporation rates. If not counteracted by increased precipitation, higher evaporation rates lead to reduced lake levels. Water levels in Lake Superior reached record low levels for the months of August and September in 2007 (Fig. 1-4). The warming found in Lake Superior is consistent with warming in lakes around the world (Schneider and Hook 2010).

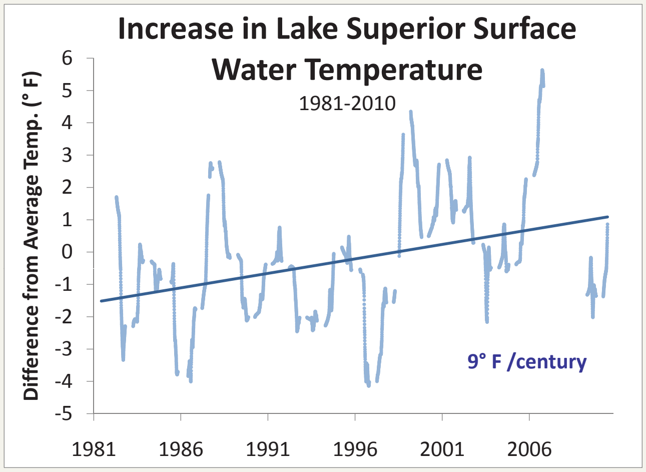


Fig. 1-3. Increase in Lake Superior surface water temperature measured at a mid-lake buoy. Expressed as the departure of annual averages from the 1981–2010 average. Rate of change per century is calculated from the data and is not a prediction. Source: Minnesota State Climatology Office, DNR Ecological and Water Resources Division; data from National Data Buoy Center.

Fig. 1-4. 2007 low water level at Lake Superior boat dock near Duluth. Photo credit: Jeff Gunderson, Minnesota Sea Grant.

Precipitation

Since 1895, annual precipitation (averaged statewide) has increased by about 3.1 inches (2.7 inches per century) (Fig. 1-5).

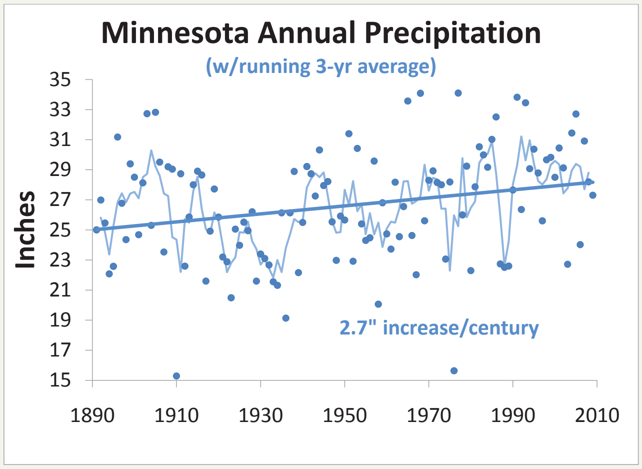


Fig. 1-5. Annual Precipitation. Rate of change per century is calculated from the data and is not a prediction. Source: Minnesota State Climatology Office, DNR Ecological and Water Resources Division.

Precipitation Variability

While precipitation has increased since the 1890s, there has been a high amount of variability over time and across space. For example, the three-year period 1987–89 contradicts the tendency toward wetter years with one of the driest three-year periods on record (Fig. 1-5). Figure 1-6 shows great variability in the precipitation change across Minnesota. Precipitation actually decreased in a few areas, though it increased over most of the state and some areas increased more than 4 inches per century. The increases along the North Shore may be due to reduced ice cover and increasing evaporation in Lake Superior.

In August 2007 a highly unusual "climate singularity" occurred, in which two parts of Minnesota were simultaneously declared disaster zones, one due to floods and the other due to drought (Fig. 1-7). This event highlights the potential variability that can occur in a single year, and also illustrates the challenge of predicting future changes.

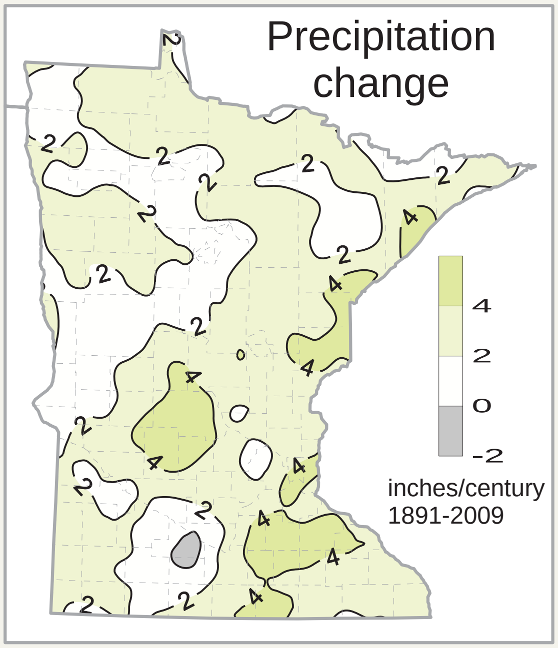


Fig. 1-6. Precipitation change in Minnesota, 1891–2009 (inches/century). Source MN State Climatology Office.

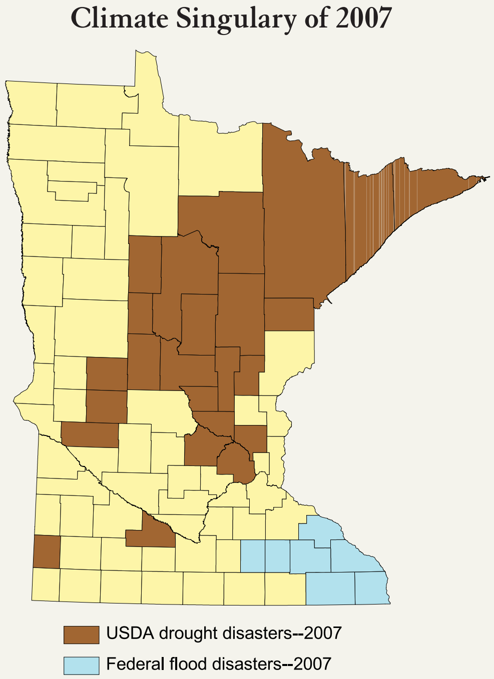


Fig. 1-7. Counties in brown were included in the Aug. 7 2007 USDA drought disaster declaration. Counties in blue were included in the Aug. 20 federal flood disaster declaration. Source: M. Seeley, University of Minnesota.

Extreme Weather Events

A regional analysis found that heavy downpours are now twice as frequent as they were a century ago in the Midwest (Karl et al. 2009). This pattern is not clear when looking at Minnesota data alone, but recent intense rainfalls are consistent with climate change predictions. There have been three 10-inch-plus rainfalls in southern Minnesota since 2004. A 10-inch rainfall has a calculated "return period" on the order of 1,000 years, which means that at any given location, such an intense rainfall has only a 0.1% chance of occurring each year.

A host of extreme weather events and climate records occurred in 2010 (all data from Minnesota State Climatology Office) :

- The earliest ice-out dates ever recorded occurred on numerous lakes.
- Forty-eight tornadoes blew through Minnesota on June 17, the highest number ever recorded on a single day. The total for 2010 (104) was also a state record.
- The lowest pressure ever recorded in Minnesota occurred on Oct. 26, 2010 at Bigfork in Itasca County (28.21 inches). Pressures this low are equivalent to those found in category 3 hurricanes.

Fig 1-8. Wave crashing over Grand Marais Lighthouse during the October 2010 "Landicane." Photo credit: Bryan Hansel, www.bryanhansel.com

Rainfall Totals for Aug. 18–20, 2007

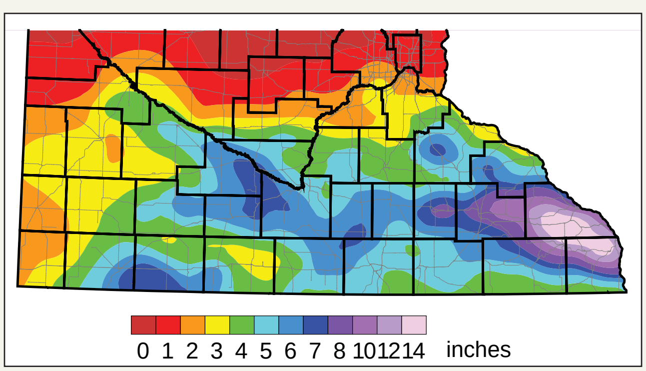


Fig. 1-9. Map of the 2007 record-breaking rainfall event in southeast MN. The largest rainfall ever recorded in a 24-hour period in Minnesota occured near Hokah (15.1 inches). Source: Minnesota State Climatology Office.

Fig. 1-10. A large tornado near Albert Lea, MN on June 16, 2010. Photo credit: Arian Schuessler, Mason City, IA Globe Gazette, used with permission.

As discussed on p. 12, *single weather events or the events of one year cannot be used to confirm or refute trends in climate*. However, climatologists understand that a warming climate increases the amount of water vapor that can exist in the atmosphere, which provides the conditions for more intense and frequent storms and rainfalls.

Fig. 1-11. Flood damage along Whitewater River exceeded $4 million at Whitewater State Park.

Future Climate Projections

According to average values of 16 climate model projections for central Minnesota, by the 2080s:

- Annual average temperatures in Minnesota will increase by 5.3–8.5° F
- Average annual precipitation will increase by 6.8–11.5%; and
- Average summer precipitation will not change significantly (Fig. 1-12).

Because of differences in assumptions and design, the 16 models vary in magnitude of projected temperature change. **Despite this uncertainty, all models project increases in average temperature, between 3°F and 12° F.**

Precipitation projections are much more uncertain than temperature projections. Annual precipitation could *increase* by up to 38% or *decrease* by up to 28%. However, average values for percent change in summer precipitation hover near zero. **If temperatures increase and summer precipitation does not increase, available soil moisture and water levels will decrease.** This would impact all habitat types, agricultural systems, and human water use.

Note that actual emissions over the past ten years were most similar to those assumed in higher emissions scenarios (Le Quere et al. 2009).

Other important projections include:

- Heat waves are expected to be more intense, more frequent, and longer lasting (Meehl et al. 2007).
- Frequency of extreme precipitation events is expected to increase, with longer intervening dry periods and increased risk of drought (Christensen et al. 2007).

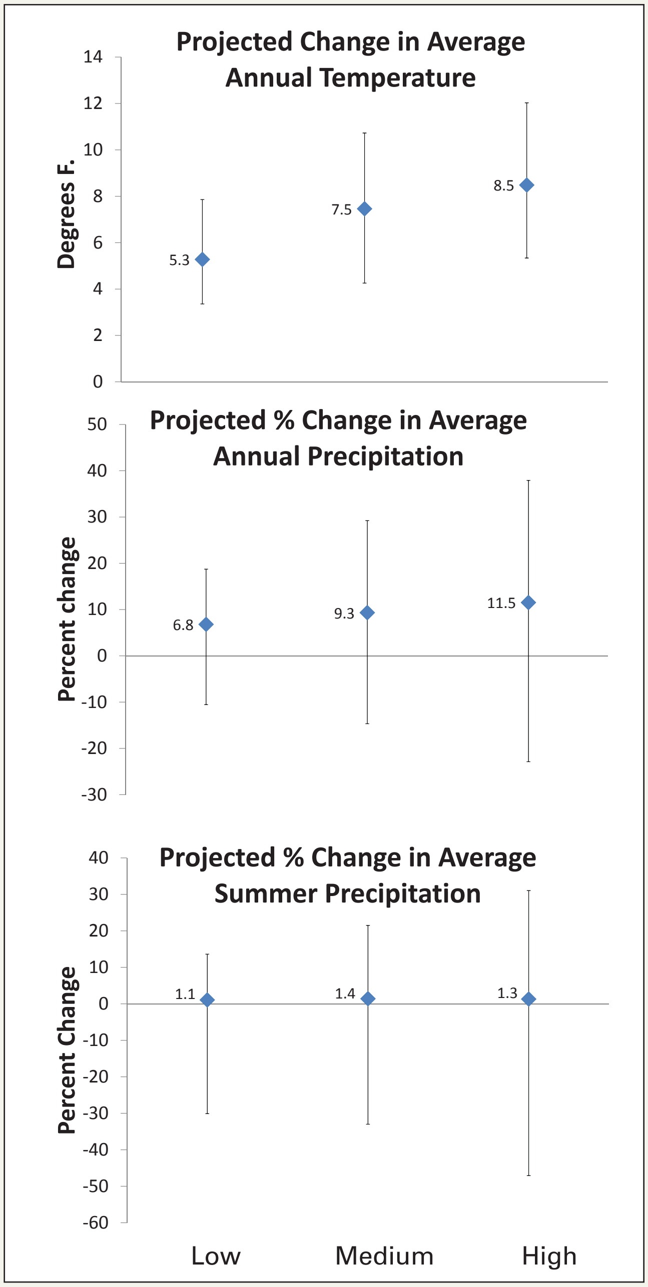


Fig. 1-12. Temperature and precipitation projections for the 2080s in central Minnesota for low, medium, and high greenhouse gas emissions scenarios (B1, A1b, and A2 scenarios, IPCC 2007a). Blue diamonds represent average values across 16 global climate models; error bars represent extremes of the 16 models. Source: University of Santa Clara Statistically Downscaled WCRP CMIP3 Climate Projections, accessed through: www.climatewizard.org.

Future Climate Analogs for Eight Minnesota Landscapes

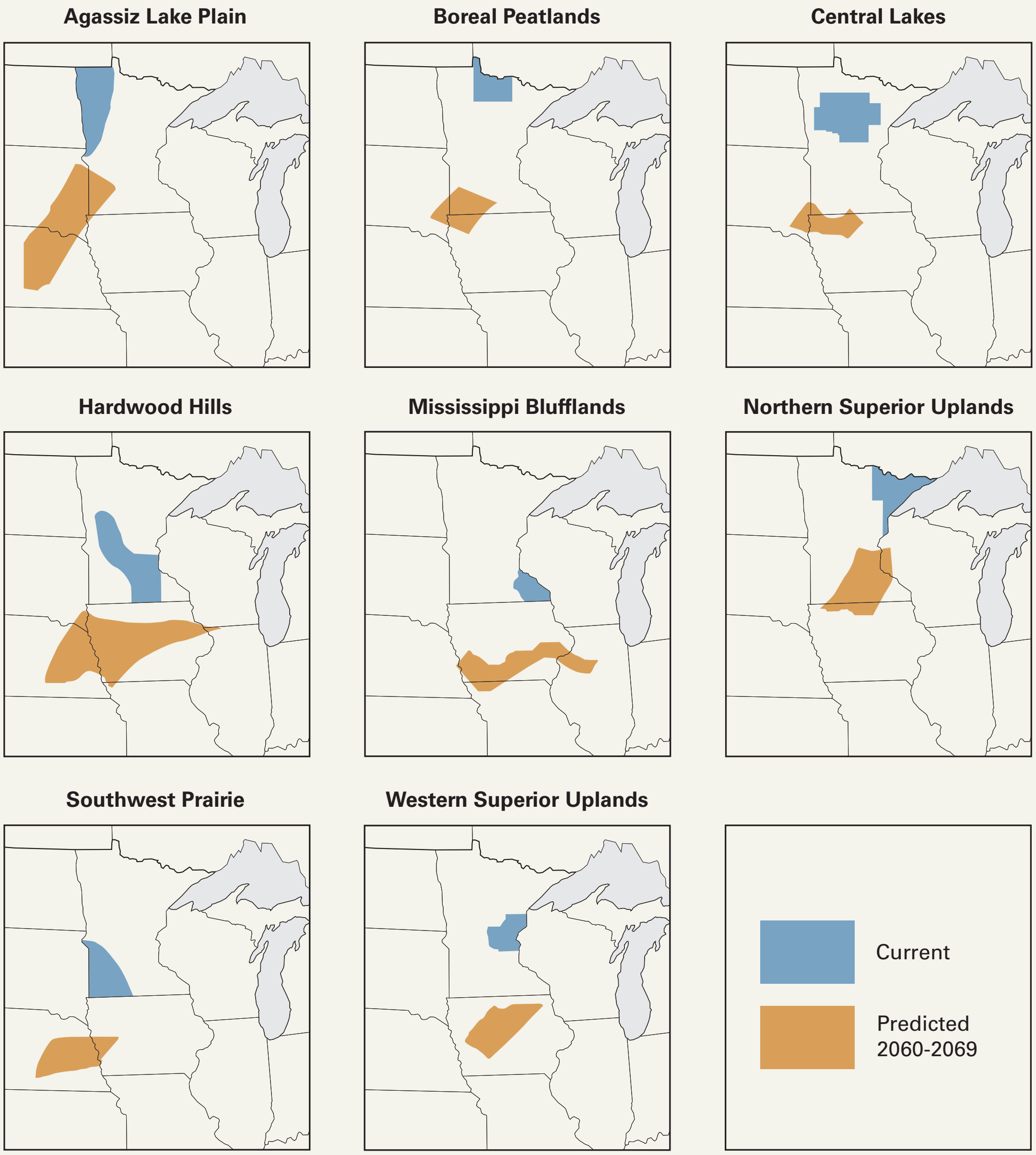


Fig. 1-13. This graphic shows analog locations (in brown) having contemporary climates most resembling the future climates projected for the 2060s in eight Minnesota landscapes (in blue). For example, in the 2060s, Minnesota's Central Lakes Landscape (upper right box) is projected to have a climate like that in contemporary northwestern Iowa (adapted from Galatowitsch et al. 2009). Projections were based on a high (A2) greenhouse gas emissions scenario (same high scenario used in projections depicted on p. 18).

Global Climate and Energy Context

Global patterns in climate and energy trends set the context for Minnesota DNR's response to these issues. The following provides the broad outline of these patterns and how they relate to Minnesota-specific trends, challenges, and opportunities.

Global Climate Trends

Global temperatures have increased steadily over the past century (Fig. 2-1). Globally, 2010 was tied with 2005 for warmest year on record. Numerous other indicators of climate change have been documented with multiple data sources (see Box 4.) These changes have been associated with increasing concentrations of greenhouse gases in the atmosphere (National Academy of Sciences 2011, Karl et al. 2009, IPCC 2007b).

United States National Academy of Sciences Report: America's Climate Choices

"Climate change is occurring, is very likely caused primarily by the emission of greenhouse gases from human activities, and poses significant risks for a range of human and natural systems. Emissions continue to increase, which will result in further change and greater risks. Responding to these risks is a crucial challenge facing the United States and the world today and for many decades to come."

Source: National Academy of Sciences 2011

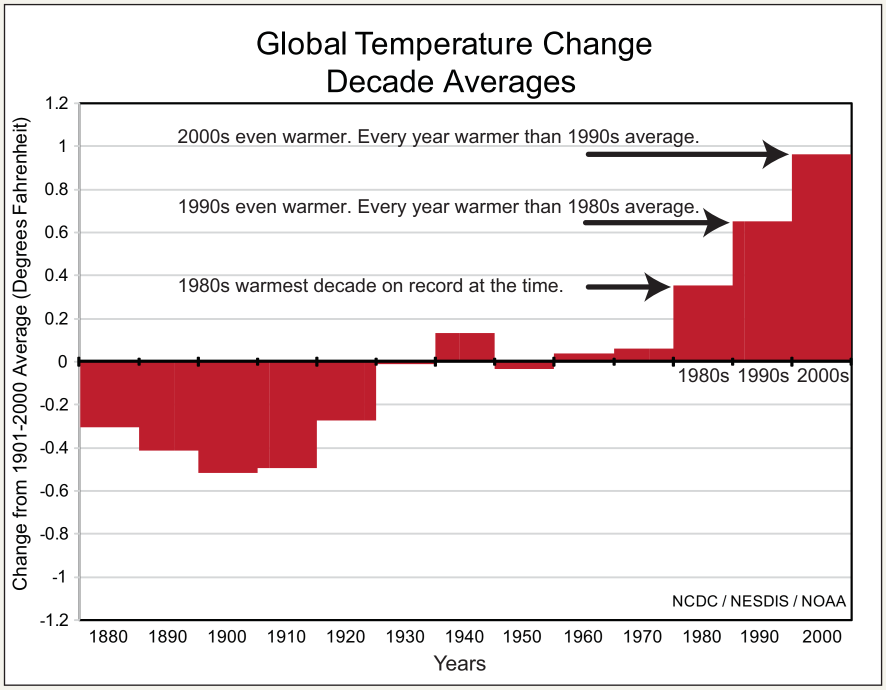


Fig. 2-1. Global Temperature Change, 1880–2010. Change is expressed as the difference from the 1901–2000 average, a typical baseline for depicting change. Source: Arndt et al. 2010, "State of the Climate in 2009, Highlights."

Box 4. Global Indicators of Climate Change—Observed Changes

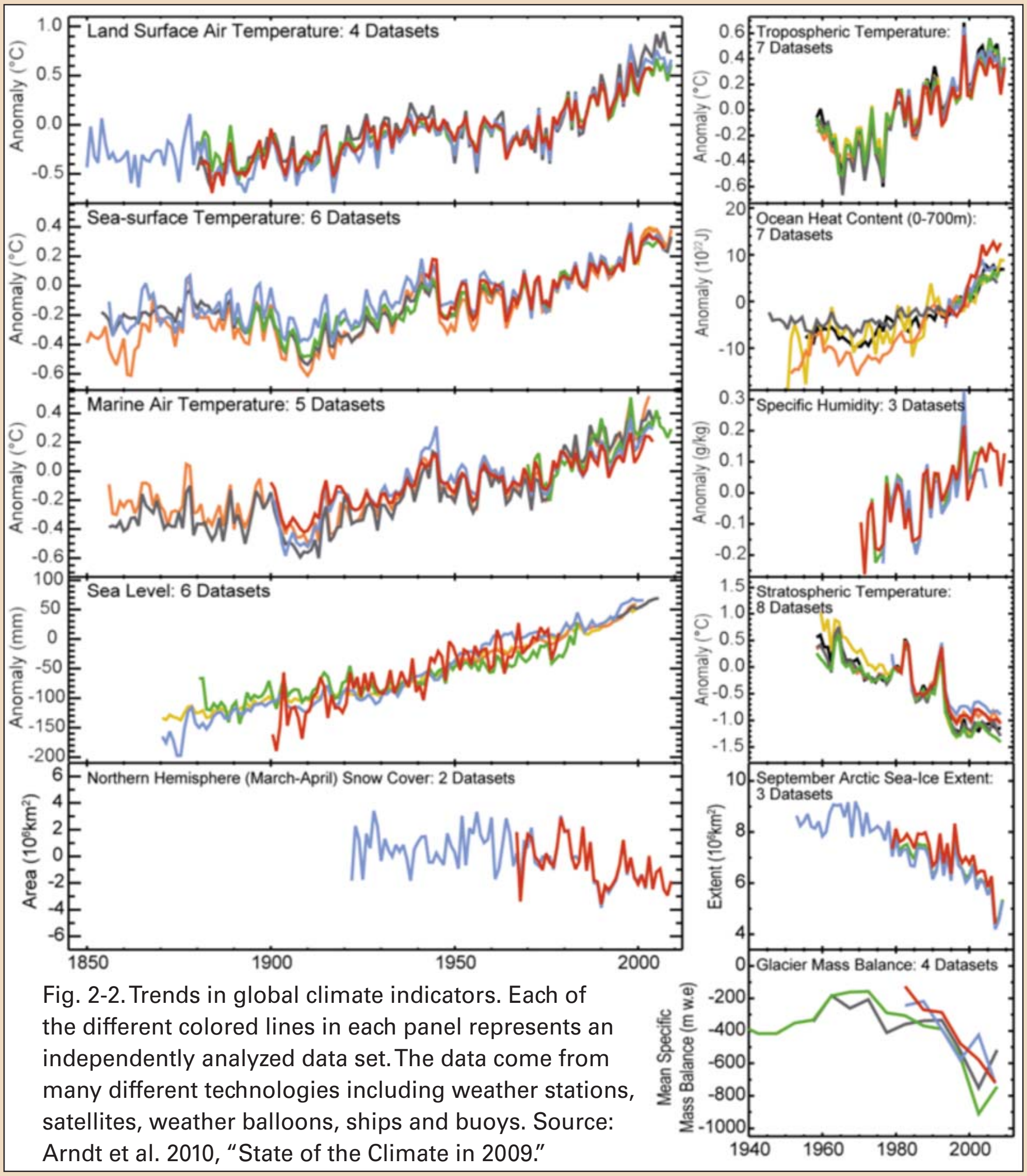


Fig. 2-2. Trends in global climate indicators. Each of the different colored lines in each panel represents an independently analyzed data set. The data come from many different technologies including weather stations, satellites, weather balloons, ships and buoys. Source: Arndt et al. 2010, "State of the Climate in 2009."

A global panel of climate scientists concluded that "warming of the climate system is unequivocal" (IPCC 2007b). The panels on this page show numerous lines of evidence for this change, based on a variety of independently analyzed data sets (different colored lines). Land-based temperature records provide only one line of evidence of warming. Other indicators include uptake of heat by oceans, glacial and Arctic sea ice melting, increased atmospheric humidity, and decreased stratospheric temperature.

A 2010 "State of the Climate Report" concludes: "The observed changes in a broad range of indicators provide a self-consistent story of a warming world." (Arndt et al. 2010).

Global to Local Energy Trends

Local, national and global economies and living standards are tied to the availability and cost of energy. Historically, energy use has been closely tied to economic growth. Even as the U.S. economy has become less energy intensive in recent decades, the total demand for energy has continued to grow. The discovery, development and integration of new energy resources into the economy have been a significant part of economic and cultural growth and evolution.

Coal, oil natural gas, large scale hydroelectric production, nuclear power and modern renewables contributed new supplies of energy to drive industrial development and economic growth from the later 19th through the 20th Century. Historically, these new energy resources have not eliminated or replaced older energy resources, but have grown the total supply of available energy. Despite other, newer energy resources, oil has remained the dominant energy resource for the U.S. and Minnesota (Fig. 2-3, 2-4).

Despite the price spikes of the 1970s, the general price trend for energy in the twentieth century was one of declining real prices. However, the first eight years of the 21st Century saw dramatic increases in the real price of energy, primarily petroleum and natural gas. The U.S. Department of Energy continues to project steadily increasing energy prices, led by petroleum products. (Fig. 2-5).

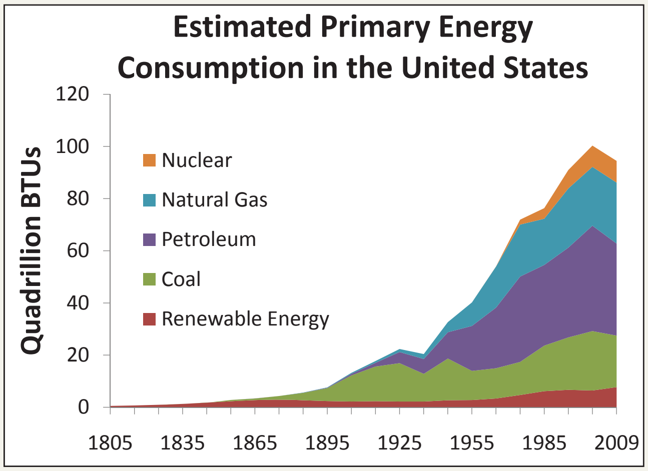


Fig. 2-3. Historically, new energy resource have not replaced, but rather added to the overall energy resources consumed by a growing U.S. Economy. Renewable energy includes: wood, hydro electric power, geothermal, wind and solar energy. Source: U.S. Department of Energy, Energy Information Administration.

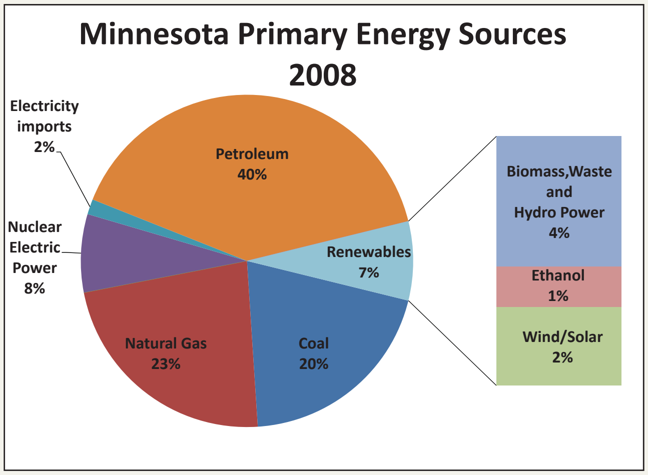


Fig. 2-4. The composition of primary energy use in Minnesota is similar to the national energy mix. Though, Minnesota is seeing strong growth in renewable energy production and use. Source: U.S. Department of Energy, Energy Information Administration.

Higher energy prices create a general drag on the economy, negatively impacting job creation and standards of living. These higher prices also exacerbate trade issues. Oil and petroleum imports are responsible for a growing share of the U.S. trade deficit (The Economist 2010). While the U.S. is still a leading oil producer, it contains only 3% of global proved reserves and still imports 51% of all petroleum products (U.S. Department of Energy 2009). The long term potential to increase domestic oil production is limited. The economic impacts of high energy prices are most acute in regions, like Minnesota, that do not possess fossil energy reserves.

Increased regulation and improved pollution control have resulted in vastly improved air quality. Yet, energy production and consumption still have significant impacts on the environment and natural resources. Vehicles, power plants and other combustion facilities are leading sources of air pollution (U.S. Environmental Protection Agency 2009). Fossil fuel burning is the most significant source of greenhouse gas emissions, globally, nationally and within the state of Minnesota. About 80% of total greenhouse gas emissions in Minnesota are attributable to energy production and use. (Strait, et al. 2008). Globally, greenhouse gas emissions continue to increase, and CO_2 emissions reached an all-time high in 2010 (International Energy Agency 2011).

Addressing energy challenges involves a range of actions and responses including more efficient use of energy, avoiding wasteful energy uses, and development of cleaner domestic energy supplies. Minnesota has been a national leader in pursing energy efficiency and renewable energy development. Minnesota's Next Generation Energy Act of 2007 focused on increasing energy efficiency, expanding community-based energy development, and establishing statewide GHG emission reduction goals of 15% by 2015, 30% by 2025, and 80% by 2050, based on 2005 levels. The Act supplements other legislation passed in 2007 mandating that 25% of Minnesota's power come from renewable sources by 2025.

Under current state and federal policies, renewable energy development will continue to grow steadily in Minnesota. DNR will play a role in reducing energy use, transitioning to renewables, increasing biomass production on state lands, and encouraging market development for biofuels.

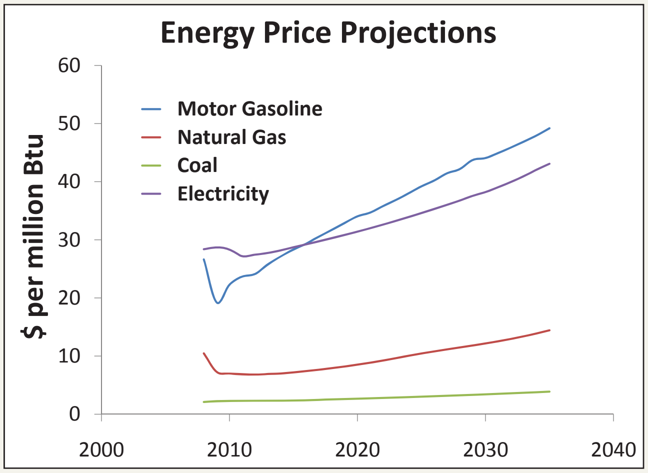


Fig. 2-5. U.S. Energy Information Administration long term price projections for key energy products averaged across user class in nominal dollars per million BTUs. Source: U.S. Department of Energy, Energy Information Administration.

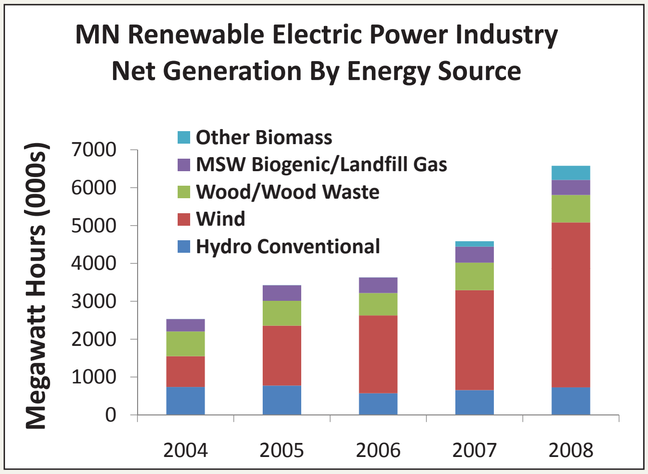


Fig. 2-6. Source: U.S. Department of Energy, Energy Information Administration Minnesota Renewable Electricity Profile 2008 Edition http://www.eia.gov/cneaf/solar.renewables/page/state_profiles/minnesota.html

Climate Change Impacts on Natural Resources

Global, National, and Regional Impacts

Globally, recent climate changes are already affecting physical and biological systems on all continents and in most oceans (Rosenzweig et al. 2007). Trends in the United States are consistent with global trends:

- Since 1981, growing season length increased by 10–14 days, and net primary productivity (NPP) increased by about 10% (Janetos et al. 2008).
- "Large-scale shifts have occurred in the ranges of species and the timing of seasons and animal migration, and are likely to continue." (Karl et al. 2009; see also Parmesan and Yohe 2003, Parmesan and Galbraith 2004).
- Climate change is an important contributing factor to increases seen in fires, insect pests, disease pathogens, and invasive weed species. These trends are likely to continue. (Karl et al. 2009).

Size of U.S. Wildfires, 1983 to 2008

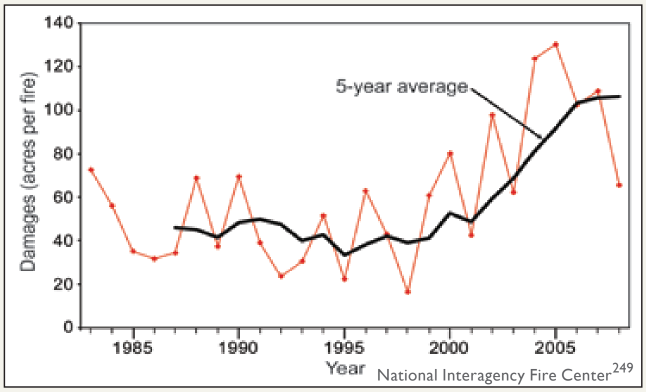


Fig. 3-1. Data on wildland fires in the United States show that the number of acres burned per fire has increased since the 1980s. Source: U.S. Global Change Research Program.

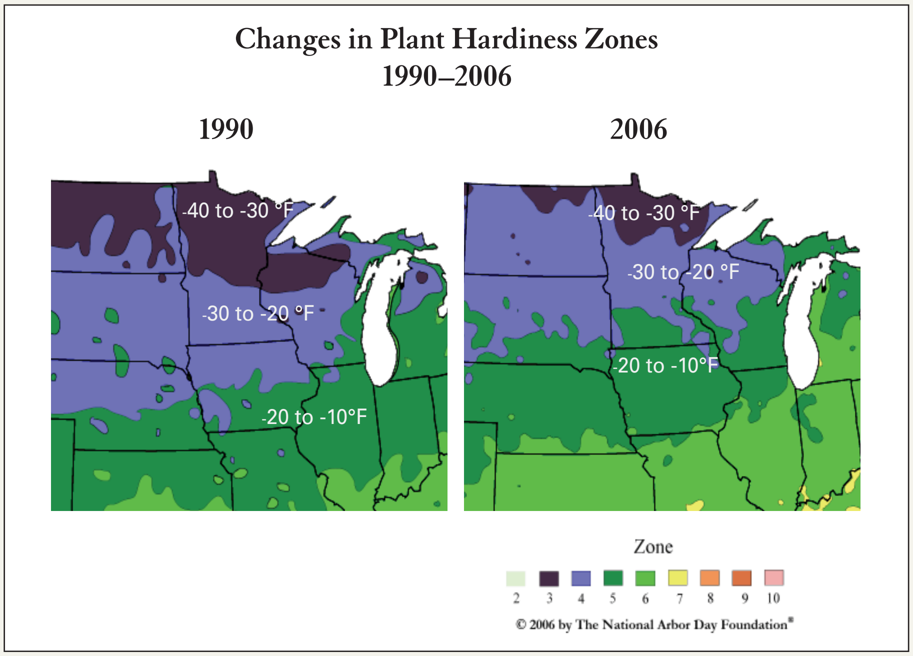


Fig. 3-2. Changes in plant hardiness zones in the Upper Midwest, 1990–2006. Zones defined by average minimum temperatures have shifted north. Note that a new hardiness zone (5) entered Minnesota by 2006 while Zone 3 retreated northward. Source: National Arbor Day Foundation.

Sensitivity of Minnesota's Resources to Climate Change

Minnesota's location, climate, and ecological features will play a major role in determining climate change impacts on natural resources. At the center of the continent, Minnesota spans a transition zone among three major biomes—tallgrass prairie, eastern broadleaf forest, and mixed coniferous forest. Because climate largely determines species ranges—and biomes defined by dominant species—climate change impacts are expected to occur relatively quickly and visibly along such transition zones. Figure 4-3 shows the southern and western range limits of several tree and plant species, superimposed over a biome map. Projected climate changes will move these range limits to the northeast.

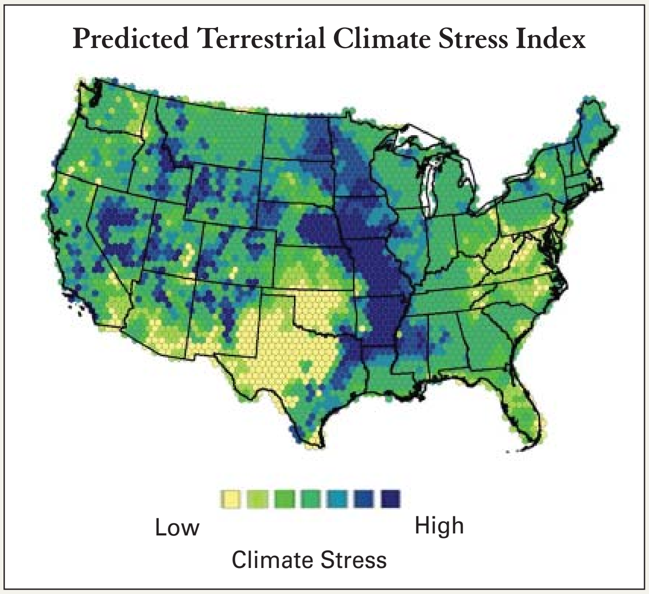


Figure 4-4. Predicted Terrestrial Climate Stress Index. Darker colors indicate area of greater predicted change between current and projected future biological communities. Source: Joyce et al. (2008).

Fig. 4-3. Climate induced range limits of common tree and plant species in Minnesota. Source: Adapted from Tester (1995).

Joyce et al. (2008) found that most of Minnesota lies in a region of higher predicted terrestrial "climate stress" (defined as the degree of change between current biological communities and those projected by future climate scenarios; see Fig. 3-4) than most of the United States. A global study by Gonzales et al. (2010) produced similar results. These studies underscore the climate sensitivity of ecological transition zones such as those found in Minnesota, where even slight climatic changes of several degrees F can cause shifts in the dominant plant communities or habitat types. Temperature and precipitation changes in the range projected by the end of the century for Minnesota will likely have major ecological impacts.

The following sections describe these potential impacts along with "early signs of change," stratified by major ecosystem type in Minnesota.

Aquatic Habitats and Species

Characteristics, Values, and Sensitivity to Climate

Minnesota's abundant aquatic resources are critical components of the state's natural heritage. More than 11,000 lakes, 65,000 miles of streams and rivers, and millions of gallons of groundwater support Minnesotans' way of life and economic vitality. Minnesota's aquatic resources provide drinking water, irrigation, habitat for numerous fish and wildlife species, a diversity of recreational opportunities, and the setting for a thriving tourism industry.

Many factors affect characteristics of aquatic systems, including geology, human disturbance, and the amount and type of vegetation in the surrounding watershed. Like Minnesota's terrestrial systems, aquatic systems vary along a climate gradient, with generally warmer waters in the south and colder waters in the north.

Air temperature is a key driver of water temperature (Stefan et al. 1996, Bogan et al. 2003, Herb and Stefan 2010), and water temperature determines which species can live in an area and how fast they can grow. For example, some Minnesota fish species, such as lake trout, require very cold water (less than 50° F) and high levels of dissolved oxygen (Dillon et al. 2003, Jacobson et al. 2010). Other Minnesota fish species, such as largemouth bass and bluegill, tolerate a wide range of water temperatures, but grow best in temperatures as warm as 82° F or more (Eaton et al. 1995, Lyons et al. 2009; Fig. 3-5).

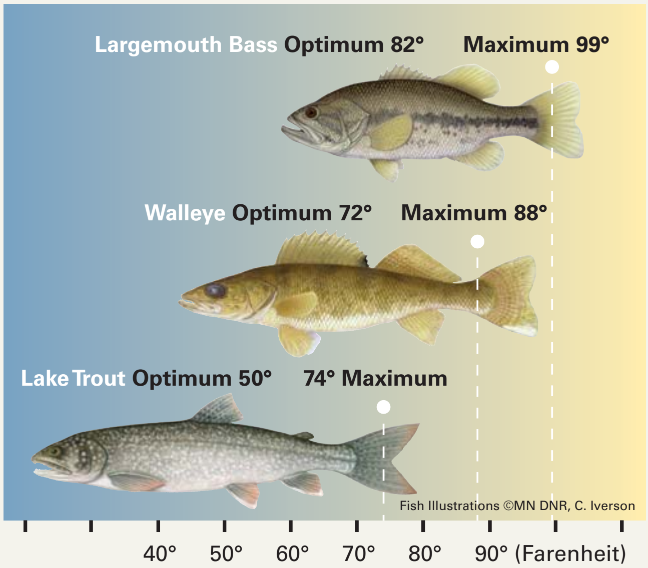


Figure 3-5. Maximum water temperatures for some Minnesota fish species.

Precipitation also affects aquatic systems: Lower precipitation can cause water levels (and thus volume of habitat) to decline, and large rainfalls can increase runoff, sediment loading, and connectivity between systems.

Early Signs of Change

We are already starting to see some climate-change impacts on aquatic systems. For example:

- In Minnesota lakes, ice-out shifted to earlier dates by 1.3 days per decade between 1965 and 2002, and ice-in shifted later by 7.5 days per decade between 1979–2002 (Johnson and Stefan 2006).
- Between 1973 and 2008, maximum seasonal ice cover on the Great Lakes declined by about 30% (Karl et al. 2009).
- Warmwater fish, notably largemouth bass and bluegill, are becoming more common in northern Minnesota lakes (Schneider 2010; DNR Fisheries unpublished survey data).
- In the 2000s, blue-green algae and diatoms bloomed in some remote wilderness lakes in Minnesota and nearby states. Such blooms have never before been recorded and are not evident in sediment cores dating back to the 1600s. Research suggests the blooms are likely caused by a warming climate (D. Engstrom unpublished data).
- In Minnesota, relative abundance of cisco in standard gillnets declined by 42% since 1975 (Fig. 3-7). Recent evidence suggests that declines are primarily due to climate change (Jacobson et al., in press). Cisco are an important food source for walleye, pike, and lake trout (see Box 10, p. 48).

- A comprehensive database of surface water temperatures is not available for Minnesota, but globally since the 1960s, surface water temperatures have warmed by 0.2 to 2°C in lakes and rivers in Europe, North America and Asia (Rosenzweig et al. 2007: 91; see also Schnieder and Hook 2010).

Fig. 3-6. Dead cisco from a large summerkill on Lake Andrusia, Beltrami County during the unusually warm summer of 2006. Photo credit Peter Jacobson MN DNR.

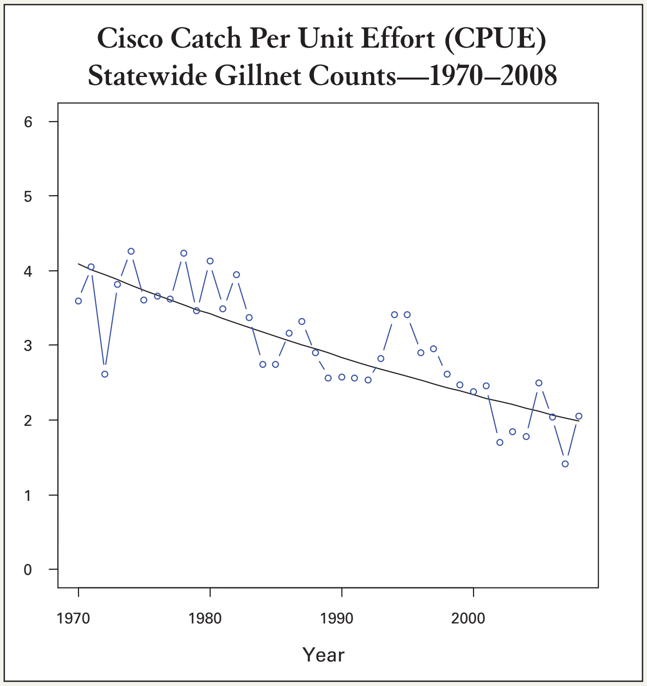


Fig. 3-7. Average annual cisco catch per unit effort (CPUE) for statewide gillnet sampling (blue circles) from 634 Minnesota lakes. Black solid line represents the estimated linear trend in statewide cisco gillnet CPUE, a decline of 13% per decade for the period 1970–2008.

- Between 1953 and 2002, 69% of 36 stream gauging stations in Minnesota showed increases in mean annual flow. For the stations with increases, mean annual flow increased by 2% per year (Novotny and Stephan 2007).

Likely Future Impacts

Over the next 50–100 years, impacts associated with projected climate changes will likely be more extreme than those already observed.

Physical and hydrological changes

Warmer air temperatures, besides bringing warmer water temperatures, will bring longer ice-free periods and growing seasons. Lake levels are expected to decrease over the long term due to higher evaporation from higher temperatures and longer ice-free periods. Stronger and longer periods of stratification will increase the risk of oxygen depletion and formation of deep-water "dead zones" (Kling et al. 2003). Upland streams and shallow lakes are more likely to become intermittent streams and dry lands than lower main-stem rivers and drainage lakes (Kling et al. 2003).

Though some aspects of water quality have improved in many lakes and streams since pollution-control laws were enacted, climate change will likely challenge our ability to continue these improvements. Greater frequency of intense storm events will increase runoff and nutrient loading from surrounding watersheds, and flooding will alter stream channels and substrate. Deleterious cyanobacteria (blue-green algae) blooms are expected to increase in Minnesota (Paerl and Huisman 2008, 2009). In general, these stressors will produce warmer, more nutrient-enriched (eutrophic) waters in most lakes and streams, exacerbating the impacts of other stressors such as overexploitation of fish populations; runoff from impervious surfaces, feedlots, and crop fields; and removal of in-lake and stream habitat such as aquatic plants and coarse woody habitat.

Some lakes and streams will be more resilient to climate change than others, including large, deep lakes with balanced food webs and relatively low levels of nutrients (Stefan et al. 2001, Beisner et al. 2003, Genkai-Kato and Carpenter 2005, Jacobson et al. 2010). Streams with significant groundwater inputs, channels shaded by trees, intact floodplains and meanders, and watersheds with deep-rooted perennial vegetation will be more resilient to atmospheric temperature changes and surface flow variability (Chu et al. 2008, Palmer et al. 2009).

Invasive species

Invasive species aggressively exploit disturbed habitats optimal for their growth, typically leading to declines or losses of native species. Climate change may reduce habitat suitability for native species and open up new niches for invasive species to exploit (Walther et al. 2009). More than two dozen invasive aquatic species and diseases are of immediate concern to Minnesota DNR (Box 5; http://www.dnr.state.mn.us/invasives/index.html) and many more are likely to become a concern as habitats continue to be altered by climate and land use, and highly mobile humans and global commerce serve as vectors of spread.

Fish species ranges, abundance, and growth rates

Projected hydrological and physical changes to aquatic systems will alter habitat suitability for many native and nonnative fish species (Schindler 2001, Kling et al. 2003, Ficke et al. 2007). Changes in habitat suitability will bring changes in fish ranges, abundance, and growth rates. In general, a northward migration of species ranges will occur due to warming waters, and the trend already seen for warm-water species such

Box 5. Case Study: Climate Change is Expected to Increase Range and Abundance of Nonnative Invasive Eurasian Watermilfoil and Curly-leaf Pondweed

Eurasian watermilfoil, an invasive nonnative aquatic plant, was first detected in Minnesota in 1987. As of 2010, the plant has spread to 246 water bodies in Minnesota and often dominates the aquatic plant community in lakes with moderate nutrient levels shortly after introduction. Curly-leaf pondweed, another nonnative invasive, has been present in Minnesota since around 1910 and probably was introduced with common carp. Curly-leaf pondweed has been documented in over 725 water bodies in Minnesota as of 2010 and is more widespread than Eurasian watermilfoil. Both Eurasian watermilfoil and curly-leaf pondweed thrive in productive waters and often displace native plants. Nevertheless, both plants often co-exist with native plants and are less prominent in low to moderately productive waters. Although plant-dependent native fish species utilize both Eurasian watermilfoil and curly-leaf pondweed for habitat, these plants provide lower quality fish habitat than native aquatic plants.

Both plants are “evergreen” perennials and require a small amount of sunlight under ice to maintain baseline metabolism (Smith and Barko 1990; Bolduan et al. 1994). Historically normal Minnesota winters with snow-covered ice are believed to limit their viability and competitive advantage over native plants that store nutrients and go dormant over winter. Shorter, less snowy winters may widen the range of suitable habitats for these species. Curly-leaf pondweed is becoming more prominent in northern Minnesota lakes, where it was hardly detected in the past.

Although longer growing seasons will probably lead to increases in these invasive plants, minimizing external nutrient additions through best management practices and minimizing in-lake removal of aquatic plants may limit changes in vegetation and fisheries of our lakes under a warmer and more variable climate.

as bass and sunfish in Minnesota will continue (Rahel 2002, Kling et al. 2003). Cold-water species such as burbot (eelpout), lake whitefish, cisco (tullibee), and lake trout are also expected to shift their range northward and will likely decline further, especially in shallow to moderately deep northern Minnesota lakes (Stefan et al. 2001; Jacobson et al. 2010). However, in Lake Superior, temperatures are expected to warm just enough to produce more optimal conditions for cold-water species such as lake trout and whitefish, and they may actually increase (Magnuson et al. 1990).

Effects on cool-water species such as walleye, yellow perch, and northern pike are expected to be variable and complex. In cold northern Minnesota lakes, good growth habitat volume for these species may increase (Stefan et al. 2001; Fang et al. 2004), but competition and predation by warm-water species such as large and smallmouth bass may affect populations (Fayram et al. 2005, Minns 2009). Overall production of cool-water fish is expected to decline in central and southern Minnesota lakes if water temperatures exceed optimal growth conditions (Gao and Stefan 1998).

Climate change will affect stream habitats through changes in water temperature and patterns of flow (Bogan et al. 2003, Mohseni et al. 2003, Johnson and Stefan 2006). Habitat for coldwater species such as brook trout will contract while barriers to migration (e.g., dams, unsuitable stream reaches) will limit the ability of coldwater species to migrate to more suitable habitats (Meisner 1990, Eaton and Scheller 1996, Ficke et al. 2007).

Groundwater sustains most Minnesota coldwater stream fish species (Wang et al. 2003). Through higher air temperatures and evaporation, altered and more extreme precipitation patterns, increased impervious surface, agricultural drainage, and human demands on aquifers for potable water and irrigation, groundwater base flows are likely to decrease and temperatures increase over time, reducing the amount of habitat available to coldwater species (Ficke et al. 2007, Herb and Stefan 2010). Climate change and human alterations to watersheds are also expected to increase flood events, altering sediment and nutrient transport, channel morphology, and habitat suitability for native fish species (Kling et al. 2003).

Net outcome

The net outcome of climate change on lakes and stream species will likely be complex. Lakes and streams may become more nutrient rich and polluted by algae blooms and temperature-dependent or mediated contaminants and pathogens. Nonnative species that tolerate warm water and pollution, such as zebra mussels, common carp (Kling et al. 2003), Eurasian watermilfoil, and curly-leaf pondweed will likely increase (Box 5). Some fish species will adapt. Some populations will be lost and others will thrive as baseline ecosystem conditions shift (Jackson and Mandrak 2002, Walther et al. 2009, Lyons et al. 2010). Productive capacity of some current fisheries will likely be reduced under future climate scenarios, but will ultimately depend on the interplay among losses of native species, replacement by new species, and losses or pressures from non-climate human stressors (Minns 2009). In general, many native species intolerant to disturbance will be replaced with fewer nonnative or opportunistic species (Walther et al. 2009), resulting in a net loss of native fish species and overall species diversity.

Recreational impacts

Climate change will likely impact many recreational opportunities in aquatic systems. The number of swimmable waters in Minnesota may decline due to contaminants delivered by higher flows and warm-water pathogens. Ice-fishing seasons will be truncated or lost entirely from some areas of the state. Nevertheless, new recreation opportunities will arise, such as angling potential for bass and other species such as black crappies, white bass, catfish, and nonnative species such as common carp. Walleye populations may decrease, though walleye will likely continue to figure prominently in Minnesota's fishing pantheon.

Box 6. Impacts of Climate Change on Surface and Groundwater

A recent national report states that "Climate change has already altered, and will continue to alter, the water cycle, affecting where, when, and how much water is available for all uses" (Karl et al. 2009: 41). In Minnesota, the water cycle plays a critical role in all of the ecosystems and habitat types discussed in this report. The amount of precipitation is a key determinant of plant distribution and habitat type. Frequency and intensity of precipitation events also affect water availability and quality for industrial, agricultural, and recreational uses. Flooding can have profound impacts on Minnesota's communities (Fig. 3-10).

Observed, climate-related trends in the hydrological cycle in Minnesota include increases in annual precipitation, (p. 15, this report), increased stream flow (Novotny and Stefan 2007), and reduction in annual ice cover (p. 26, this report). Projected future climate changes expected to have significant impacts on Minnesota's surface and groundwater resources include increases in overall precipitation (p. 18, this report), increases in heavy precipitation events (Fig. 3-8) and increases in annual runoff (Karl et al. 2009, Milly et al. 2008).

These impacts will interact with and exacerbate existing stresses on Minnesota's water resources. Any activity that alters the movement of water across or through the landscape can have a long-term impact on the state's surface water and groundwater resources. For example, in many locations water flows off the landscape more rapidly than it did in the past, because of drain tiling for agriculture or increases in impervious surfaces brought by development. When water flows more rapidly, runoff pollution and erosion increase, as does the potential for flooding. If climate change increases heavy rainfall events, these problems will increase as well. In another example, longer growing seasons brought by climate change may increase

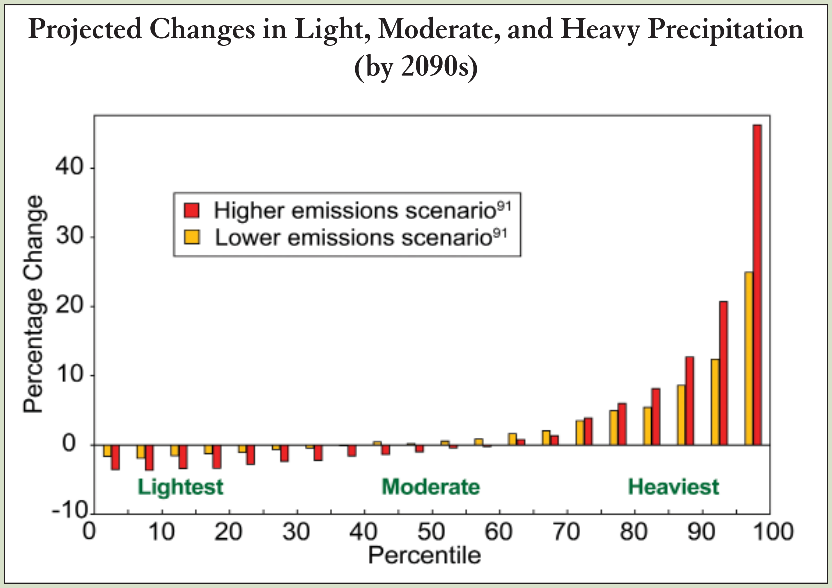


Fig. 3-8. The graph shows projected changes compared to the 1990s average in the amount of precipitation falling in light, moderate, and heavy events in North America. Changes are displayed in 5% increments from the lightest drizzles to the heaviest downpours. The lightest precipitation is projected to decrease, while the heaviest is projected to increase. Source: Karl et al. 2009.

Surface and Groundwater—Continued

irrigation demand on groundwater supplies (Wisconsin Initiative on Climate Change Impacts 2010), and many of Minnesota's groundwater resources are already stressed. Increasing demands on groundwater supplies are expected in the future (Minnesota DNR 2010a).

Climate change compounded by other stresses will create new water management challenges requiring DNR and partners to accelerate watershed-wide approaches that restore natural vegetation, slow runoff, and reduce flood risks. As water managers look forward, they need to understand that the climate of the past century is no longer a reasonable guide to the future for water management (Karl et al. 2009).

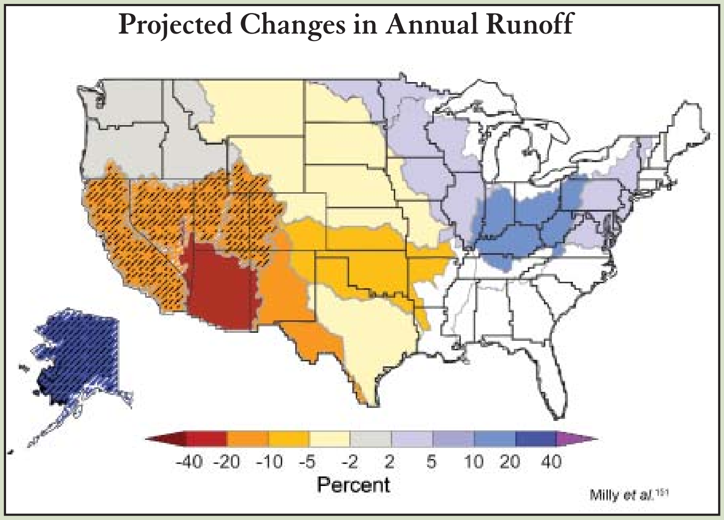


Fig. 3-9. Projected changes in median runoff for 2041–2060, relative to a 1901–1970 baseline, mapped by water-resource region. Colors indicate percentage changes in runoff (5–10% for Minnesota). Results are based on mid-level emissions scenarios. Source: Karl et al. 2009, Milly et al. 2008.

Fig. 3-10. Flood in Rushford, MN, 2007. Projected increases in heavy precipitation and runoff would lead to increased flooding.

Wetland Systems, Habitats, and Species

General

Despite the loss of about half of the wetlands present before European settlement, wetlands still comprise 20% of Minnesota's surface (Kloiber 2010). The inundated or saturated conditions found in wetlands are responsible for the development of hydric soils and characteristic wetland plant communities, all of which combine to provide many important ecosystem services, including water quality maintenance and improvement, water storage, fish and wildlife habitat, streamflow maintenance, and carbon storage. Changes in temperature and precipitation patterns associated with climate change have the potential to alter the abundance, distribution, and diversity of wetland types in the state, as well as disrupt the physical, chemical, and biological processes that generate ecosystem services.

Early Signs of Change

As with aquatic systems, we are starting to see climate change impacts in wetland systems:

- Between 1906–2000, the western portion of the prairie pothole region became drier, while the eastern portion became wetter. If this moisture gradient continues to steepen, acreage of productive wetlands will shrink (Millet et al. 2009).
- Between 1939 and 2001, 11 of 21 waterfowl species at Delta Marsh, Manitoba shifted their spring arrival dates earlier by 6–32 days (Murphy-Classen et al. 2005).
- Centers of winter distribution for ring-necked ducks, red-breasted mergansers, American black ducks, and green-winged teal all moved more than 150 miles north over the last 40 years (Niven et al. 2009a, 2009b).

Fig. 3-11. Historic and simulated change in optimal waterfowl breeding conditions in the Prairie Pothole region under a 5.4° F warming scenario (lower end of temperature projections for 2080s, see p. 18). This scenario could shrink and shift optimal waterfowl breeding conditions into western Minnesota, but most of Minnesota's wetlands have been drained. Without major wetland restoration efforts in Minnesota, the prairie pothole "duck factory" could largely disappear. Source: Johnson et al. 2005. Map by Matt Kania.

cut 2 lines

Likely Future Impacts

Prairie pothole wetlands

Due to a variety of glacial features, southern and western Minnesota is characterized by rolling topography and numerous water-holding depressions. This area is part of the prairie pothole region of North America, which extends from northern Iowa through the Dakotas and into Canada (Fig. 3-11). As a result of the varied topography and diverse combinations of groundwater interaction and precipitation/evapotranspiration rates, prairie potholes reflect a range of wetland types, from temporary, seasonal basins to semi-permanent and permanent marshes and shallow lakes (van der Valk 1989). Correspondingly, these wetlands provide habitat for many species of wildlife, particularly waterfowl and shorebirds. Most of the prairie pothole wetlands in Minnesota have been drained for agriculture, with more than 90% of the presettlement wetland area lost in some counties (Anderson and Craig 1984). However, considerable acreage remains, and many conservation programs are actively restoring these wetlands and associated grasslands.

There have been several studies and simulations of the potential effects of climate change on prairie pothole wetlands. Nearly all suggest that projected climate change will bring soil moisture declines, fewer wetlands, shorter hydroperiods, more variation in the extent of surface water, and changes in depth, salinity, temperature, and plant community composition (Browne and Dell 2007; Poiani and Johnson 1991; Larsen 1995; Poiani et al. 1995, 1996; Johnson et al. 2005, 2010, Galatowitsch et al. 2009).

Simulations of future climatic conditions in the prairie pothole region suggest that the hydrologic conditions responsible for creating the currently optimal waterfowl breeding habitat in the Dakotas may shift eastward into western Minnesota and Iowa by the end of the century (Johnson et al. 2005, 2010). Under this projected scenario of more frequent wet-dry cycles, habitat conditions for Minnesota's prairie wetlands may improve. But, as noted previously, the great majority of the wetlands in the prairie region of Minnesota have been drained (Anderson and Craig 1984), and future climatic conditions may facilitate additional drainage.

Another potential adverse factor is that "flashy" hydrologic regimes resulting from more intense precipitation events and the overall drier conditions expected under future climatic conditions will be conducive to replacement of native plant communities with invasive species, particularly reed canarygrass (*Phalaris arundinacea*) and potentially hybrid cattail (*Typha x glauca*; Galatowitsch et al. 2009, 1999).

High populations of certain fish species (common carp, black bullhead, white suckers, fathead minnows) have been observed, through various mechanisms, to have adverse effects on marshes and shallow lakes, often nearly eliminating rooted aquatic plants that are critical for wildlife habitat (Bouffard and Hanson 1997; Jackson et al. 2010; Zimmer et al. 2006). Higher winter temperatures and shorter periods of ice cover expected due to climate change may reduce the frequency of low winter oxygen conditions responsible for reducing or eliminating fish populations (winterkill; Fang and Stefan 2000). Consequently, many shallow lake systems that never consistently supported fish populations due to regular winterkill conditions may become suitable habitats for fish in the future, with potential adverse consequences for wildlife habitat and water quality. Furthermore, greater flood events and agricultural ditching practices that increase wetland connectedness may lead to greater wetland permanence and more widespread distribution of wetland habitat-damaging fish species (Herwig et al. 2010). For basins that are not easily recolonized by fish, it's possible that more frequent cycling through wet and dry stages may eliminate or reduce existing fish populations, thereby improving their condition. The actual (vs. predicted) effects of climate change on prairie wetlands and shallow lakes affected by fish populations will ultimately depend on the magnitude of observed temperature increases, changes in the amount, frequency and timing of precipitation, and associated changes in land use.

Prairie pothole wetlands also play a significant role in greenhouse gas exchange. Although peatlands are typically considered the major carbon sink among wetland types, prairie pothole wetlands sequester a significant amount of carbon as well; restoring drained and cultivated wetlands could allow them to store even more. Euliss et al. (2006) calculated that restoring farmed prairie wetlands in North America has the potential to sequester 378 teragrams (Tg) of organic carbon over a 10-year period. However, prairie wetlands also emit methane and nitrous oxide, potent greenhouse gases. Production of these gases depends on highly variable soil and moisture factors, and the net carbon balance of prairie pothole wetlands is difficult to ascertain (Bridgham et al. 2006; Dunmola et al. 2010). Restored prairie wetlands are more likely to have net positive climate effects by focusing on seasonal, temporary and semipermanent basins, which typically emit less methane than permanently inundated systems, and by establishing grassland buffers around restored wetlands to reduce inflow of nitrogen-based fertilizers that have been shown to increase methane and nitrous oxide formation (Euliss et al. 2006).

Peatlands

While nearly all wetlands accumulate organic matter that could be considered peat, the term *peatlands* generally refers to the large, mostly boreal expanse of wetlands that are characterized by deep peat deposits, often called bogs and fens (Mitsch & Gosselink 2000). Peat formation in these systems is driven by cool temperatures, saturated conditions, and low pH that inhibit decomposition. Peatlands are globally important pools of carbon, occupying about 3% of the earth's surface while containing about one-third of the total soil carbon pool (Gorham 1991). Although peatlands emit methane, an important greenhouse gas that contributes to global warming, the climate-changing impacts of peatland methane emissions appear to have historically been more than offset by the long-term, steady accumulation of carbon (Frolking and Roulet 2007). Minnesota contains 6 to 7 million acres of peatlands, more than any state other than Alaska (Glaser 1987, Minnesota DNR 1984) and therefore plays an important role in

Fig. 3-12. Northern Minnesota peatland.

global climate dynamics (for more discussion of carbon dynamics and terms, see Carbon Sequestration section, this report).

Predicting the effects of climate change on Minnesota's peatlands is challenging. Some studies suggest that peatlands are resilient ecosystems, capable of maintaining themselves under certain levels of climatic disturbance (Dise 2009). However, long-term and/or sufficiently large changes in temperature and hydrology may potentially alter plant species composition, plant productivity, evapotranspiration, and decomposition rates. Under extreme scenarios of increased temperature and periodic summer drought, peat formation may cease and existing peat stores may begin to oxidize, changing Minnesota peatlands from carbon sinks to carbon sources (Gorham 1991). This process could be accelerated by an increased frequency of peat fires, which could be more likely to occur under future climatic conditions (Parish et al. 2007).

In an experimental manipulation of temperature and hydrology, Minnesota bog and fen communities responded by altering their plant community structure, suggesting that in the most likely scenario of warmer temperatures and stable or very slightly increased growing season precipitation, Minnesota's current open bogs are likely to shift to shrub-dominated communities (Weltzin et al. 2000). On the other hand, forested peatlands may experience increased tree mortality due to drought (Galatowitsch et al. 2009). These changes have potential implications for statewide biological diversity, wildlife habitat and forest-product economies.

Finally, projected climate scenarios may facilitate further attempts to drain Minnesota peatlands for agriculture. Bradof (1992) evaluated peatland drainage methods related to the Red Lake peatlands and concluded that due to topography and underlying deposits, "… the conversion of Red Lake peatland to agricultural land could not be accomplished in any reasonable manner unless a shift to warmer, drier climatic conditions were to occur."

Calcareous Fens

Calcareous fens are rare and distinctive wetlands characterized by a substrate of nonacidic peat and dependent on a constant supply of cold, oxygen-poor groundwater rich in calcium and magnesium bicarbonates (Eggers and Reed 1997). This calcium-rich environment supports a plant community dominated by "calciphiles," or calcium-loving species, several of which are state-listed rare species. These fens typically occur on slight slopes where upwelling water eventually drains away and where surface water inputs are minimal (Almendinger and Leete 1998a, 1998b). Globally rare, nearly 200 calcareous fens or fen complexes occur in Minnesota, mostly along the Glacial Lake Agassiz beach ridges, along the Minnesota River Valley, and associated with the karst topography of southeastern Minnesota (Minnesota DNR 2009).

Under climate change scenarios of higher temperatures and reduced or more intense precipitation events that allow less groundwater infiltration, the groundwater discharge responsible for supporting calcareous fens could be reduced or eliminated in some areas (Galatowitsch et al. 2009).

Riparian and Floodplain Wetlands

Riparian wetlands are shallow areas along the margins of lakes and streams that support rooted aquatic vegetation. Floodplain wetlands, typically forested, occur along but outside the banks of streams and rivers and are supported by periodic inundation due to flooding. Both of these wetland types are important components of the energy and nutrient pathways of their associated lake and river systems, and provide important fish and wildlife habitat (Naiman et al. 2005; Mitsch and Gosselink 2000).

The plant species composition of floodplain wetlands depends on the timing, frequency, and duration of inundation. Projected changes in precipitation patterns under future climate scenarios may alter hydrologic regimes of floodplain wetlands, possibly resulting in more frequent but shorter duration flooding. Floodplain wetland hydrologic regimes may also be indirectly altered due to changes in stream morphology (downcutting, meander cutoffs) that affect the frequency of out-of-channel flood events. As a result of these potential changes in hydrology, floodplain wetland communities within localized areas may be modified and perhaps gradually converted to non-wetland.

Riparian wetlands along the margins of lakes and streams may be affected by changes in water depths and hydroperiods that may occur under future climatic patterns, particularly becoming more vulnerable to invasive species such as reed canary grass (*Phalaris arundinacea*). Increased erosion and sedimentation that may result from more intense rainfall could also adversely affect riparian wetlands. The University of Minnesota Water Resources Center is currently investigating potential climate change impacts on shoreline plants (University of Minnesota 2010).

Forest Systems, Habitats, and Species

Characteristics, Values, and Sensitivity to Climate

Minnesota's forested ecosystems provide a wealth of ecological, recreational, and economic benefits to the citizens of the state. Of the approximately 16.7 million acres of forested land in Minnesota, approximately 57% is in public ownership. Approximately 2.8 million cords of wood was used by industry and as fuelwood in 2008. Tourism, much of which occurs in the forested parts of the state, is an $11 billion industry. Forest ecosystems are heavily used for recreational activities such as birdwatching, hunting, fishing, hiking, snowmobiling, and trail riding. Minnesota's forest ecosystems provide a variety of ecosystem services that maintain the production of wildlife, timber, and biomass fuels. Forest ecosystem services also include helping purify air and water, mitigating floods and drought, generating and preserving soils and their fertility, sequestering carbon, maintaining biodiversity, and providing people with aesthetic beauty and intellectual stimulation.

Variation in climate, physiography, soils, and disturbance along geographic and site-level gradients determines the distribution of 107 different forest and woodland native plant communities in the state. These communities range from wet, nutrient-rich southern floodplain forests to dry, nutrient-poor northern pine forests. A few of the native plant communities are globally imperiled, and many are rare in the state. Approximately two-thirds of the state's 292 documented animal species addressed in the state wildlife plan (species of greatest conservation need) occur in Laurentian Mixed Forest and Eastern Broadleaf Forest Provinces.

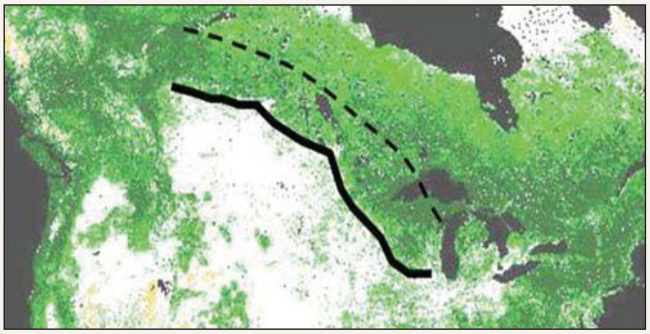


Fig. 3-13. Over the next century, climate change may shift the prairie-forest border 300 miles to the northeast. The dark line is the current prairie-forest border; the dashed line represents the possible future border. Similar shifts have occurred during past warming episodes. Source: adapted from Frelich and Reich 2010.

In general, forest systems, especially boreal systems near the borders of other biomes, are globally viewed as highly vulnerable to climate change (Parry et al. 2007; Gonzalez 2010; Joyce 2008). The prairie-forest border in Minnesota is one of the most visible climatic signatures in North America, one that is particularly sensitive to climate change (Fig. 3-13).

Early Signs of Change

As in other systems, we are starting to see impacts of climate change on forests:

- Woodall et al. (2009) found strong evidence that eleven northern tree species in the eastern and central U.S. are migrating north (through seed dispersal) at rates approaching 6 miles per decade.
- Near Duluth, several common migratory forest birds are arriving 5 to 10 days earlier in the spring than they did 30 years ago (J. Green data).
- Since the 1960s, 84% of resident forest birds in the U.S. have shifted their winter ranges north by an average distance of 75 miles (Niven et al. 2009).
- Minnesota's northwestern moose population declined by more than 90% since the 1980s, most likely due to climate change-related heat stress and associated factors (DNR data, Murray et al. 2006). The northeastern population is now declining as well. New research focuses on understanding the relationship between climate and moose populations.
- Over the past 10 years, the eastern larch beetle has killed tamarack trees on over 100,000 acres in Minnesota. Increased mortality may be partially explained by warming winter temperatures, which

allow a greater proportion of eastern larch beetle adults to survive the winter. (Venette et al. 2008).

- Shorter winters are reducing the available time for winter logging, essentially reducing accessible timber supply. This stresses an already troubled forest products industry in northern Minnesota.

Likely Future Impacts

Climate change will likely affect both the nature and extent of Minnesota's forests. Although increased warming is highly likely, considerable uncertainty remains about whether precipitation will increase with temperature. If precipitation declines or remains about the same, the extent of Minnesota forests will shrink, to be replaced by savannas, grasslands, or brushlands, some dominated by invasive species (Fig. 3-13). Significant increases in precipitation coupled with warmer temperatures would create a climate still favorable for forests, but dominant tree species would shift to those with more southerly ranges (e.g., central hardwoods such as oaks and hickories; Fig. 3-14).

Warmer temperatures in Minnesota's forest regions are likely to be accompanied by more frequent extreme weather events. Droughts and floods are predicted to be more frequent, severe, and long lasting. More frequent natural disturbance events, such forest fires, blowdowns, and ice storms, coupled with increased insect outbreaks, will lead to increased tree mortality.

Species shifts

The fossil record has demonstrated that species respond to global warming by slowly shifting their ranges toward the poles. In Minnesota, future climate conditions for species such as balsam fir, aspen, and white spruce will be less favorable than current conditions, and, under the highest emissions scenarios, some boreal species may be extirpated from the state (Galatowitsch et al. 2009). Conversely, the future climate may be more favorable for oaks and hickories, and some southern species that are not currently present may move into the state. Table 4-2 shows projected changes in habitat suitability for tree species in northern

Table. 3-1. Projected climate-change induced changes in habitat suitability for tree species in Northern Wisconsin over the next 100 years (Swantston et al. 2010). Predictions for Minnesota are expected to be similar, with some exceptions (e.g., sugar maple, red oak, and red maple will likely increase in northern Minnesota, but decrease in other parts of the state. The USFS plans to conduct a similar analysis for Minnesota, in partnership with DNR and other groups.

Direction and Magnitude of projected change	Tree species
Large Decrease	mountain maple, black spruce, balsam fir, paper birch, yellow birch, eastern hemlock, quaking aspen, northern white cedar, bigtooth aspen, sugar maple, white spruce, black ash, tamarack
Small Decrease	butternut, eastern white pine, red maple, rock elm, jack pine, balsam poplar
No Change	chokecherry, red pine, northern red oak, northern pin oak, American basswood, green ash
Small Increase	white ash, eastern hophornbeam, American hornbeam, American elm
Large Increase	black cherry, bur oak, american beech, white oak, bitternut hickory, black oak, boxelder, swamp white oak, shagbark hickory, silver maple, black willow, slippery elm, eastern cottonwood, osage orange, eastern red cedar, black walnut, hackberry

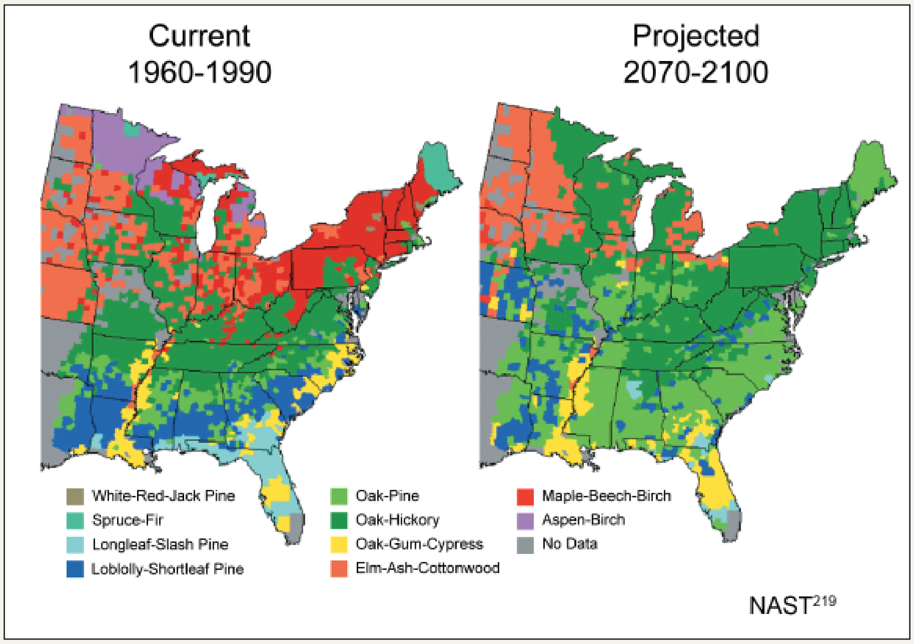


Fig. 3-14. Current and projected forest types under a mid-range warming scenario. Aspen-Birch forests in Minnesota may be replaced by Oak-Hickory forests. Source: National Assessment Synthesis Team 2001, as used in Karl et al. 2009.

Wisconsin (USFS Chequamegon-Nicolet Assessment); the U.S. Forest Service plans to conduct a similar analysis for Minnesota. The ability of tree species (and other forest plant species) to shift their ranges in response to climate change, however, is contingent on dispersal as well as changes to disturbance patterns and their ability to compete with invasive species. Forest species do not migrate as intact communities; instead, each species with its unique ecological requirements moves at its own rate and sometimes different species move in opposite directions. Thus, even in the absence of barriers to dispersal (e.g., habitat fragmentation), changes in disturbance patterns, and competition from invasive species, existing forest ecosystems will likely be replaced by novel ecosystems with species assemblages having no historical precedent.

Loss of connectivity

Many Minnesota forests are fragmented due to agriculture, development, and forest management, reducing ecological connectivity within the landscape. Such fragmentation is most pronounced in the southern and western portions of the state, but even in northern Minnesota where forests are relatively intact, habitat fragmentation has eliminated the majority of large patches, reducing ecological connectivity. This loss of connectivity will limit the ability of some forest species to disperse in response to climate change.

Invasive species

Invasive species such as buckthorn and garlic mustard will become a larger component of what are now forest ecosystems. These species are already widespread in southern Minnesota, and populations are increasing in the north. With increased disturbance and drought, these and other invasive species are expected to disrupt existing species assemblages, potentially becoming dominant species in some areas. Other invasive species such as kudzu (*Pueraria montana var. lobata*) may migrate north into Minnesota, further altering Minnesota's forest ecosystems.

Insects and disease

Because insects typically have short generation times and high reproductive rates, they can respond rapidly to climate change, allowing them to expand into forest communities that have previously been outside their range Logan et al. 2003). Increased winter temperatures and droughts predicted for Minnesota will not only make the climatic conditions more favorable for newly arrived and existing insects and diseases, but will also stress trees, leaving them more susceptible to mortality. Warmer winters have allowed range expansion of mountain pine beetles in western Canada, where an unprecedented outbreak exceeded 32 million acres and timber losses were over 120 million cords (Kurz et al. 2008). In the future, warm winters may allow the mountain pine beetle to cross Canadian boreal

Box 7. Phenological Mismatches

Phenology is the study of the timing of recurring plant and animal life-cycle changes, such as leafing and flowering in plants, animal migration, or insect emergence. These events are often linked with weather and climate. Phenological responses to climate change will differ among species. Some species will significantly alter the timing of migration, breeding, or flowering, while others will respond slightly or not at all. As a result, climate change can cause phenological mismatches among species and the resources they need to breed or survive. For example, a phenological mismatch is likely causing local extinctions of the Edith's checkerspot butterfly in the southern part of its range in Mexico and California. Because of earlier seasonal warming and drying, the host plants of this species dry out too soon and the caterpillars cannot find enough food to survive (Parmesan and Galbraith 2004). While phenological mismatches have not been investigated in Minnesota, they are a potential outcome of climate change. This raises the importance of monitoring phenology across a wide array of species and habitats (see Box 8, also see the USA National Phenology Network: USANPN.org).

forest and become established in Minnesota, bringing high mortality to jack and red pines. Other insects and diseases, including those currently present in the state and those that will arrive in the future, will continue to alter existing and future forest ecosystems.

Net outcome

Climate change will likely have extensive or even profound impacts on Minnesota forests, depending on amount of warming and extent and direction of precipitation change. Warming itself will cause shifts in species ranges and reductions in commercially important tree species such as aspen and white spruce. Warming combined with reduced precipitation would shift the current location of the prairie-forest border to the northeast, which would have dramatic impacts on ecosystems, forest-based recreation opportunities, and the timber economy. In all scenarios, invasive species are predicted to increase. The challenge for resource management is how to intervene in this dynamically unfolding and uncertain system.

Fig. 3-15. Paper birch forest in northern Minnesota. Paper birch are expected to decline with climate change.

Prairie Systems, Habitats, and Species

Characteristics

Prairie communities occur throughout much of Minnesota, though mainly in the western one-third of the state. Historically, prairies occurred where precipitation, fire frequency, and local hydrology precluded forests or wetlands. Prairie communities range from the wet, nutrient-rich southern wet prairie to nutrient-poor northern dry prairie. Because of conversion to agriculture and other land uses, nearly 99% of Minnesota's original native prairies have been lost, and most remaining prairies are small and isolated (Fig. 3-16). Approximately half of the state's 292 documented animal species addressed in the state wildlife plan (species of greatest conservation need) occur in the Prairie Parkland Province. Statewide, prairies contain more species of greatest conservation need than any other habitat in Minnesota (Minnesota Department of Natural Resources 2006).

Early Signs of Change

Scientists and managers are beginning to detect signs of climate change in prairies. Some of these signs are not yet established as long-term trends, but they are consistent with climate change predictions and need to be monitored as we plan for the future. Noted changes include:

- In Bluestem Prairie in western Minnesota, the pasque flower is blooming two weeks earlier than it did a century ago (S. Travers and O.A. Stevens data).
- In the northern prairie region, 18 out of 20 migratory bird species shifted to earlier migration dates. These shifts were correlated with increases in winter temperatures, and species associated with aquatic habitats responded more strongly (Swanson and Palmer 2009).

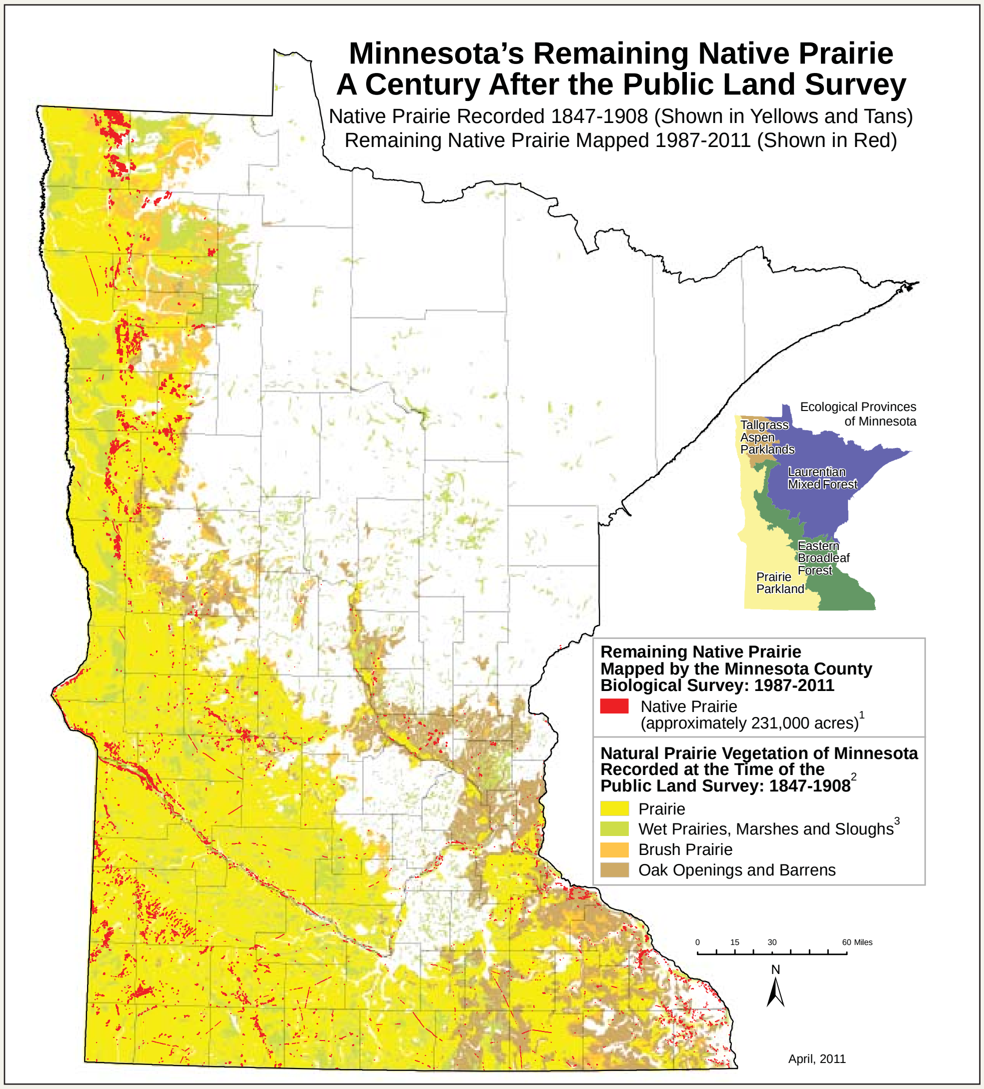


Fig. 3-16. Minnesota's remaining native prairies. Source: Minnesota County Biological Survey.

- The federally threatened western prairie fringed orchid (*Platanthera praeclara*) is declining, especially in the southern portion of its range (Nebraska, Kansas). While the causes of the decline are numerous, this species is sensitive to changes in precipitation and temperature. Droughts lasting more than one year are known to severely increase mortality and reduce flowering of surviving plants (Nancy Sather personal communication; DNR Rare Species Guide).

Likely Future Impacts

Predicted temperature increases, changes in precipitation, and increases in extreme weather events are projected to affect prairie systems in a variety of ways. As with other systems, uncertainty in precipitation projections makes it difficult to predict climate change impacts on prairies. However, climate model averaging suggests that either slight decreases (Galatowitsch et al. 2009, Christensen et al. 2007) or essentially no change in summer precipitation (see Climate Projections section, p. 18) are the most likely scenarios in Minnesota's prairie region. Both scenarios combined with temperature increases would result in net drying in summer, likely causing increases in fire frequency and generally shifting the prairie forest border to the northeast. These changes may actually bring an increase in suitable conditions for prairies, but these conditions will not automatically produce new native prairies, and the changes will not be positive for all prairie habitats.

Fig. 3-17. Western prairie fringed orchid.

Potential losses

Increases in net drying would cause gradual shifts in plant composition including eventual declines of mesic and wet prairie species. Isolated and mesic prairies with low diversity will be most susceptible to the impacts of climate change and compounding factors such as invasive species. Southwestern Minnesota will likely lose unique wet prairie systems as they dry because of the isolated nature of these systems. Rare species such as Wolf's spikerush (*Eleocharis wolfii*) will be vulnerable to extinction as conditions change and microhabitats such as ephemeral pools within rock outcrops no longer retain enough water seasonally to sustain these species. Price (1995) modeled the summer distributions of 23 species of North American grassland birds. The results indicate that summer distributions of all 23 species will shift, and several species would likely be extirpated, resulting in substantial changes in grassland bird communities.

Potential gains

While mesic and wet prairie species may decline with climate change, dry prairies may increase. Prairies with high species diversity and physiographic variability may transition fairly smoothly from mesic to dry prairie systems. Woodlands may shift to prairies, and this will occur most readily in areas were these two systems occur in close proximity (Galatowitsch et al. 2009). As existing wetland systems dry, suitable habitat for prairie species may increase in these locations.

Constraints on transitions to prairie

The combination of existing fragmentation and isolation of most prairie remnants, the limited dispersal ability of many prairie plants, and increases in invasive species will limit the ability of prairie systems to expand into areas that become more suitable for prairie.

Fragmentation.— Minnesota's prairie landscape is highly fragmented (Fig. 3-17). Even without climate change, this fragmentation poses a significant threat to prairies. Over 90% of the original mosaic of prairie, wetland, and forest in the prairie province has been converted to agriculture or development. While climate change will likely create new areas with suitable conditions for prairie, it will be difficult for many prairie species to move into these new areas because they have limited dispersal abilities, and the non-prairie areas between prairie fragments function as dispersal barriers.

Invasive species.— Invasive species are widespread throughout the prairie landscape. Invasive species, including cool-season grasses such as smooth brome (*Bromus inermis*) and perennial and annual forbs such as spotted knapweed (*Centaurea biebersteinii*), wild carrot (*Daucus carota*) and leafy spurge (*Euphorbia esula*), pose considerable threats to the existing native prairie. With increased disturbance caused by climate change, these and other invasive species will continue to disrupt native species assemblages and potentially dominate sites (MacDougall et al. 2005, Hanson and Weltzin 2000).

Net outcome

The impact of climate change will be coupled with existing stresses brought by fragmentation and invasive species. Climate change will exacerbate these stresses as habitat becomes less suitable for some existing species and fragmentation hampers dispersal of these and other species. This dispersal roadblock will provide increased opportunities for invasive species to move into native systems (Saunders et al. 1991). The challenge for resource managers will continue to be how to effectively intervene in the face of uncertain climate conditions. Intensive management, including invasive species monitoring and control, prescribed burns, and seeding will likely be necessary to facilitate a transition from current woodlands and wetlands to future native prairies.

Box 8. Changes on Aldo Leopold's Farm

"Most phenological studies take place over a relatively short time span—fewer than 30 years. However, Bradley et al. (1999) were able to take advantage of observations on the timing of spring events made by Aldo Leopold on a Wisconsin farm in the 1930s and 1940s. Comparing Leopold's data on birds and native flowers to their own surveys in the 1980s and 1990s enabled them to look for long-term trends over a 61-year period. They found that the more recent surveys indicated that spring events for many species are taking place substantially earlier than in Leopold's time; for example, northern cardinals sing 22 days earlier, forest phlox blooms 15 days earlier, and butterfly weed blooms 18 days earlier. Of 55 species studied, 18 (35%) show advancement of spring events, while the rest show no change in timing (with the exception of cowbirds arriving later). On average, spring events occur 7.3 days earlier in the 1990s, coinciding with March temperatures being 2.8°C (5.0°F) warmer."

Source: Parmesan and Galbraith (2004).

Part II: Management Response

Management Response: Adaptation Strategies

Part II of this document describes examples of DNR's current and proposed management responses to climate change and renewable energy trends, divided into separate sections on climate-change adaptation and mitigation strategies.

A final section of **Part II** describes a decision framework for improving climate change and renewable energy strategies as we learn more.

Climate Change Adaptation

Climate change adaptation activities help human and natural systems prepare for and adjust to climate change. More formally, they "reduce the vulnerability of natural and human systems against actual or expected climate change effects" (IPCC 2007b). Adaptation strategies are typically grouped into three broad categories: resistance, resilience and facilitation (Millar et al. 2007, Galatowitsch et al. 2009). The actions that DNR can take to prepare for and adapt to the effects of climate change on Minnesota's natural resources can be grouped into these categories.

Resistance

Resistance strategies attempt to help species, communities, or systems to remain unchanged in the face of climate change (Lawler, 2009). For example, constructing seawalls to hold back rising sea levels is a resistance strategy. Resistance strategies that are (or could be) implemented in Minnesota include maintaining firebreaks around high value forests which could be at increased fire risk due to a warmer/drier climate, and aerating lakes to address hypoxia resulting from warmer waters. Resistance strategies are useful when climate change impacts are expected to be minimal or as a stopgap measure to provide time for resilience or facilitation strategies to be put into place, such as when managing an endangered species occurring within a small area.

Resilience

Resilience strategies increase the ability of species or ecosystems to absorb or adapt to the effects of climate change. Resilient systems will continue to function in the face of climate change, although possibly in different ways or with a different suite of species than in a prior state (Lawler, 2009). Systems which lack resilience will likely undergo abrupt transformations, causing disruption or loss of ecosystem functions, population declines or even loss of species. Reducing the impact of non-climate stressors such as invasive species or nutrient pollution are commonly used resilience strategies. Other resilience strategies include enlarging the sizes and numbers of protected areas through restoration or acquisition (especially those considered climate refuges, see cisco case study); increasing or maintaining the natural diversity of sites at both at the species and genetic levels, and managing for multi-age forest structure. Resilience strategies are best implemented when climate change effects are not expected to be severe, when there is a high degree of uncertainty regarding the direction of change, or as interim measures.

Facilitation

Facilitation strategies use active management to encourage adaptation toward a predicted direction of climate change. These strategies can "mimic, assist, or enable on-going natural adaptive processes such as species dispersal and migration, population mortality and colonization, changes in species dominances and community composition, and changing disturbance regimes" (Millar et al., 2007). The goal is to facilitate incremental change so as to minimize the number and scale of catastrophic "threshold" conversions of natural communities. Facilitation can be risky because it involves encouraging change toward an uncertain outcome; however, the gradual nature of facilitation may allow for redirection if necessary. Examples of facilitation strategies include establishing travel corridors in the expected direction of changes in species ranges, deliberately moving young or adults in that same direction, or introducing native species beyond their current range but within the boundaries of expected change. Another example is planting seeds or seedlings originating from seed zones that resemble the expected future conditions of the planting site (see seed control case study).

Selecting Adaptation Strategies for Resource Management

Managers need to consider impacts of climate change when developing and implementing plans to protect and conserve natural resources. The normal uncertainties inherent in resource management will be further complicated by uncertainties associated with the direction and magnitude of climate change.

Lawler et al (2009) suggests a model (Figure 4-1) for identifying the uncertainty (risk) associated with resource management. Strategies that have been successful under a relatively static climate and are likely to be successful under other climate scenarios, such as controlling terrestrial invasive species, are considered low risk (uncertainty). In contrast, activities such as species translocations, which are often unpredictable under normal climatic conditions, become even more uncertain when compounded by climate change (high risk).

An additional complicating factor for many resource managers is the uncertainty surrounding use of pre-settlement conditions as goals for restoration and management. The Society for Ecological Restoration International Primer on Ecological Restoration (2004) states, "Restoration attempts to return an ecosystem to its historic trajectory. Historic conditions are therefore the ideal starting point for restoration design." In some cases, such as for DNR's Division of Parks and Trails, this objective is mandated in statute: Minnesota Statutes, section 86A.05, subd. 2c, directs state parks to "preserve, perpetuate and interpret natural features that existed in the area of the park prior to [European] settlement" and to "re-establish desirable plants and animals that were formerly indigenous to the park but are now missing." Climate change calls for revising these guidelines.

With climate and other environmental changes, novel ecosystems (also known as no-analog systems) are emerging that differ in composition and function from present and historic systems (Hobbs et al. 2009). While change is a normal attribute of ecosystems, the rapid pace of change today increasingly brings novel environmental conditions, new species combinations, and altered ecosystem functions. Hobbs et al. (2009) suggest that managers will need to consider several potential scenarios when developing management plans, including: (1) scenarios where it is possible to maintain historic ecosystems with relatively little modification and/or addition of new species, (2) scenarios where it is not possible to maintain historic ecosystems but it is possible to maintain or restore of key structures and functions (3) scenarios where biotic and/or abiotic changes exceed ecological thresholds such that it is difficult or impossible to restore novel systems to previous states. Traditional, static views of biodiversity and ecosystems will need to be replaced with improved scientific understanding of changing ecosystems and climate in the future (Mawdsley et al. 2009).

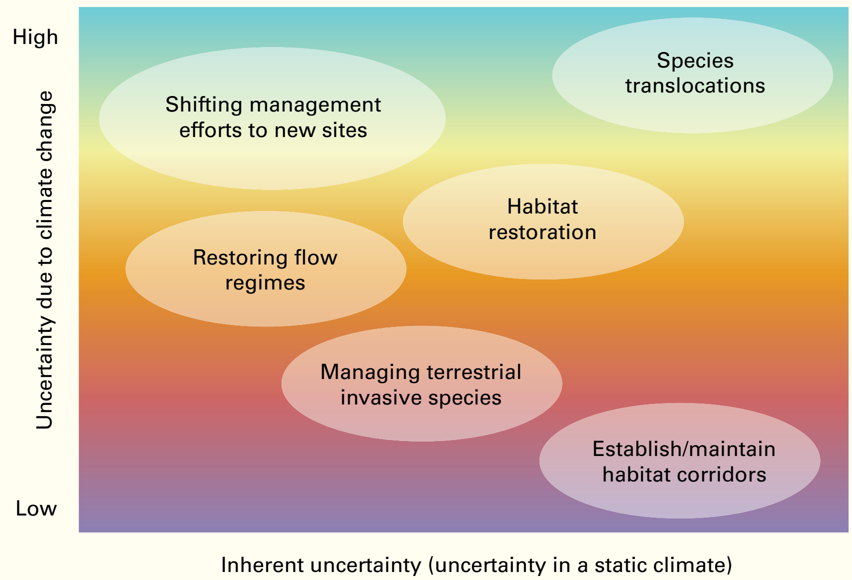


Figure 4-1. Model for considering uncertainty in management strategies for addressing climate change (Adapted from Lawler et al. 2009).

Box 9. Seed Control To Help Maintain a Resilient Forest

The DNR Nursery and Tree Improvement Program provides seeds and seedlings for reforesting harvested sites and for other conservation plantings. The program provides high quality seeds and seedlings from known locations that are likely to be adapted to the climatic and site conditions of those locations. Using seeds from plants adapted to sites where they will be planted greatly improves their chances for survival and vigorous growth. In order to provide the best seeds and seedlings to land managers and citizens, DNR's Nursery and Tree Improvement Program uses "seed source control" to track the origin of seeds and keep seeds from different locations separate so they can be planted in appropriate locations.

Minnesota has six seed zones for forest plants based on current climatic conditions (Fig 4-2). Foresters identify healthy forest stands within different zones and target them for seed collection. By obtaining seed from plants growing in a wide variety of climatic conditions with genes suitable for those conditions, we capture greater genetic diversity. After collection, the DNR Nursery program maintains source location information so seeds and seedlings can be returned to their original seed zone for planting. This helps ensure that reforestation efforts are successful.

Under a scenario of a relatively stable climate, planting seeds obtained near the intended planting zone is generally best because they are already adapted to those conditions. However, DNR is revaluating this practice in anticipation of changing climates. One alternative is to plant seeds or seedlings from seed zones that resemble the expected future conditions of the planting site. This may not be practical as a general practice because we do not know precisely how climates will change, especially regarding precipitation (see p. 18). To deal with this uncertainty, another approach is to expand seed collection zones. This increases the genetic diversity of plantings because seeds originate from a larger geographic area. Increasing the genetic diversity of plantings raises the chances that some of the trees and their offspring will survive and adapt to whatever climatic conditions arrive in the future. Both of these approaches have strong support in the literature but bring some risks and need to be carefully evaluated (Millar et al. 2007, Galatowitsch et al. 2009). As we learn more, seed source control will continue to be critical for deliberate matching of seeds from collection to planting locations, or for expanding seed zones.

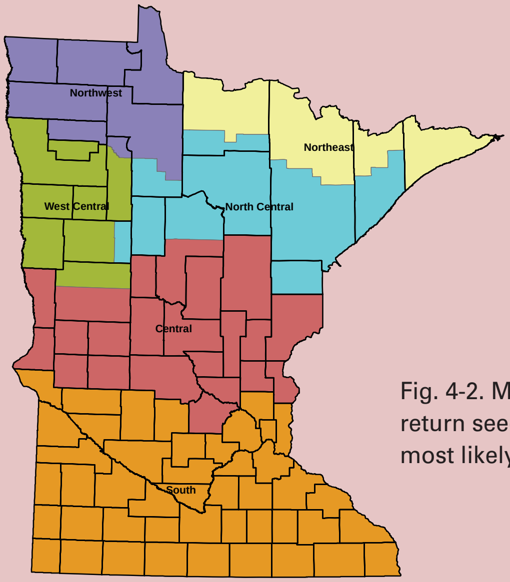


Fig. 4-2. Minnesota DNR's forest seed collection zones help return seeds and seedlings to locations where they are most likely to thrive.

In a recent survey (MNDNR 2010), DNR staff identified 1) protecting/enhancing/restoring native habitats, 2) optimizing groundwater recharge, and 3) protecting/enhancing/restoring corridors for movement of species as the most important adaptation strategies from a list of 18 choices (Table 7-1). Of those, the first and third could be considered "medium uncertainty" because of the uncertainty surrounding selection of appropriate restoration targets in a changing climate and the potential for corridors to facilitate introduction/spread of invasive species into new areas. DNR staff also identified establishment of captive populations and artificial transport of species as the least important strategies of those included in the survey. Both of these could be considered "high uncertainty" because of the inherent risks of trying to move or establish populations of species and the uncertainty regarding where the most suitable areas will be.

Climate change challenges resource managers to adapt to both a swiftly changing climate and a high level of uncertainty. Given this environment, Heller and Zavaleta (2008) recommend that resource managers implement a range of measures, from low-risk, precautionary actions to high-risk efforts that are particularly anticipatory in nature.

Implementation of precautionary actions such as

Table 4-1. Levels of Uncertainty for Selected Adaptation Strategies

Adaptation Strategy	Low Uncertainty	Medium Uncertainty	High Uncertainty
Protect/enhance/restore native habitats.		X	
Optimize groundwater recharge.	X		
Protect/enhance/restore corridors for movement of species		X	
Expand long-term monitoring of populations, habitats & other natural resources.	X		
Protect/enhance/restore hydrologic regimes.	X		
Maintain genetic diversity in seed sources.		X	
Maintain viable populations of species	X		
Adjust forest management prescriptions		X	
Maintain native species communities through ongoing management interventions	X		
Increase private lands conservation assistance.	X		
Optimize ditch & shore land buffers.	X		
Use vegetation management strategies to closely mimic natural disturbances.	X		
Protect/enhance/restore potential refuge areas.		X	
Intensify terrestrial invasive species prevention & control.	X		
Conduct vulnerability assessments	X		
Increase land acquisition/easements	X		
Establish captive populations of species that would otherwise go extinct.			X
Facilitate movement of species to more suitable geographic areas through artificial transport			X

This table identifies likely levels of uncertainty of achieving the expected outcome of an adaptation strategy in the face of both climate change and the "normal" uncertainty of the outcome under a stable climate.

management strategies that mimic natural ecological processes (e.g., prescribed burning, wetland and shoreline restoration) will continue to help managers address current threats to natural resources and may make communities more resilient to climate change. However, these efforts alone will not address the long-term changes in ecosystem composition that will occur as a result of shifts in temperature and precipitation. Strategies such as using seed mixtures suitable to the expected climate, increased efforts to connect landscapes, and facilitated migration will also be needed to meet these challenges.

Over the past two decades, researchers have developed a substantial literature on conservation management in the face of climate change. In their review of 112 papers, Heller and Zavaleta (2008) summarize four recommendations that consistently appear: 1) coordinate among area agencies and organizations to improve landscape connectivity, 2) widen the temporal and spatial criteria for projects and incorporate actions that build resilience, 3) ensure that climate change is incorporated into all resource management planning, and 4) manage multiple threats simultaneously. Solutions to climate change and other environmental issues increasingly rely on collaborating across boundaries of management areas and adjacent ownerships. This will require new connections with landowners, local officials, and citizens.

Box 10. An Adaptation Strategy for Cisco in Minnesota: Protecting Resilience in Deep, Clear Lakes Using a Landscape Approach

Cisco, the most common coldwater fish in Minnesota, are found in 648 lakes throughout the state. Cisco are an important food source for game fish such as walleye, pike, and lake trout. In fact, recent research suggests that cisco are especially important for producing large walleyes in many lakes (Henderson et al. 2004).

Because Minnesota is in the southern part of its range, cisco are especially vulnerable to climate change (Jacobson et al. 2010). Longer and warmer summers deplete oxygen in deep lakes (De Stasio et al. 1996; Stefan et al. 1996) and can lead to summer kills of cisco (Jacobson et al. 2008). Indeed, DNR records show that cisco numbers have been declining statewide since 1975 (see p. 27, this report). Jacobson et al. (in press) present strong evidence that the declines are primarily due to climate-driven stressors and not accelerated nutrient loading or invasions by non-native competitors.

DNR is developing measures to reduce the impact of climate change on coldwater fish such as cisco. Deep lakes with exceptional water quality will be important sanctuaries for coldwater fish in a warmer Minnesota. In collaboration with Heinz Stefan at the University of Minnesota and Xing Fang at Auburn University, DNR identified 238 deep, clear “refuge” lakes (Fig. 4-3). The majority of these lakes are in the forested areas of Minnesota where water quality remains high. Tier 1 lakes are the deepest and clearest of the refuge lakes and represent some of the real “jewels” of Minnesota including: Big Trout Lake near Brainerd, Big Sand Lake near Park Rapids, Ten Mile Lake near Hackensack, Trout Lake near Grand Rapids, Snowbank Lake near Ely, and Sea Gull Lake near Grand Marias. Tier 2 lakes will also provide habitat for cisco, but are not as deep and clear as Tier 1 lakes. Protecting water quality in these lakes and surrounding watersheds is a “resilience strategy” essential for maintaining populations of coldwater fish in the face of climate change.

Cisco Case Study—Continued

DNR (and partners such as BWSR) are developing plans to protect the surrounding watersheds through conservation easements and best management practices. Fortunately, many of the refuge lake catchments already have high levels of protection (Fig. 4-3). The Superior National Forest provides a great deal of protection in the northeast part of the state. The Chippewa National Forest, state forests, and county tax-forfeit lands provide additional protection in north central Minnesota. In fact, 116 lakes already have sufficient protection (>75% of the entire watershed in protected ownership). Of the remaining lakes, 101 are in the forested portion of Minnesota and would greatly benefit from private forest conservation easements. An additional 393,431 acres of forest easements would need to be purchased within the watersheds of these lakes to provide protection at the 75% level. Annual investments of $14.8 million for private forest conservation easements (@$750/acre) for 20 years would fully protect these 101 lakes (for a total of 217 refuge lakes with enhanced resilience to climate change). Despite such measures, climate change will undoubtedly reduce the number of lakes that sustain cisco. Ongoing DNR efforts are identifying imperiled lakes to help shape agency and public expectations, and inform adaptive measures (e.g., managing for alternate, warm water prey species to sustain game fish populations).

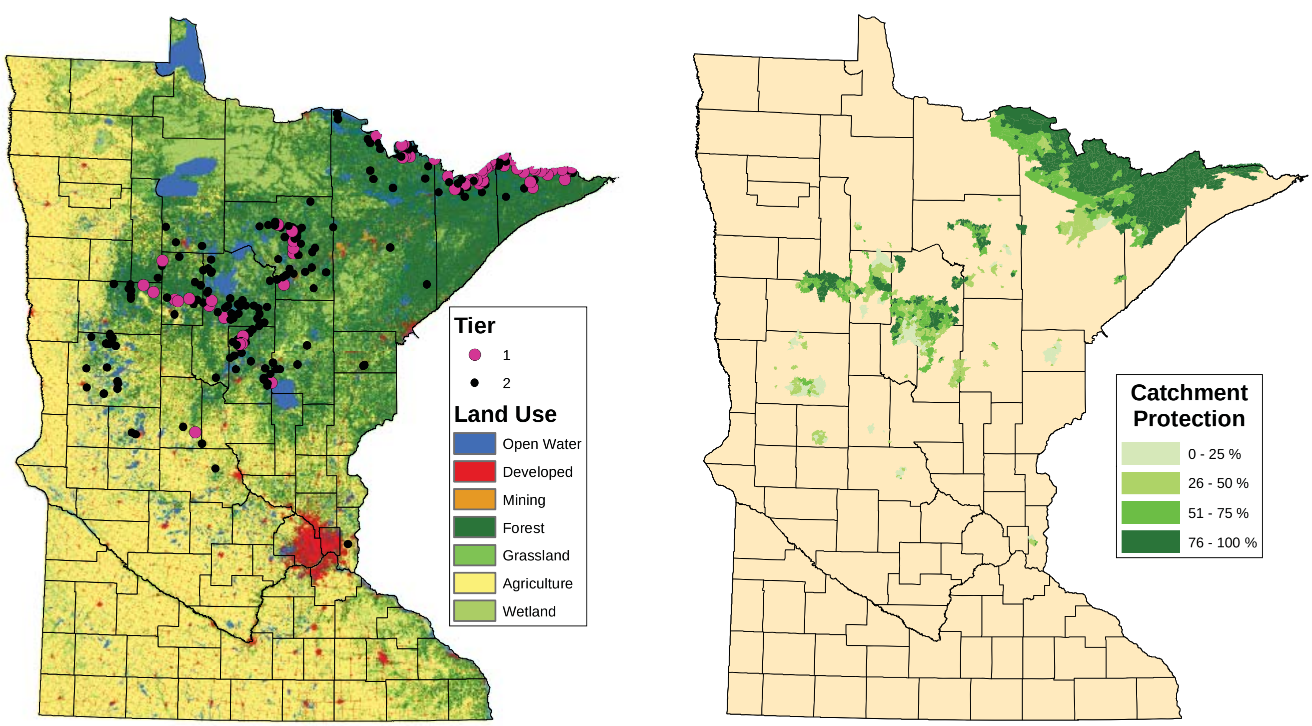


Fig. 4-3. Locations of lakes that will be sufficiently deep and clear to provide refuge for cisco from climate warming (left map, magenta and black dots). The right map displays all of the individual catchments that drain into refuge lakes, along with existing levels of land protection.

Management Response: Mitigation Strategies

Mitigation

Climate change mitigation actions are those that reduce greenhouse gas (GHG) emissions or remove them from the atmosphere. This section focuses on DNR's three primary mitigation strategies:

- Carbon Sequestration
- Bioenergy and Conservation-Based Energy Strategies
- Energy Efficiency

Carbon Sequestration

What is carbon sequestration and why is it important?

Terrestrial carbon sequestration is a natural process—driven by photosynthesis—that removes carbon dioxide from the atmosphere and stores it in plants or soils. Geologic carbon sequestration is the human-mediated process of capturing industrial CO_2 and storing it in geological formations (also known as "carbon capture and storage," or CCS). Geological carbon sequestration is beyond the scope of DNR management activities, so this section will focus on terrestrial carbon sequestration.

Forest Carbon Cycle

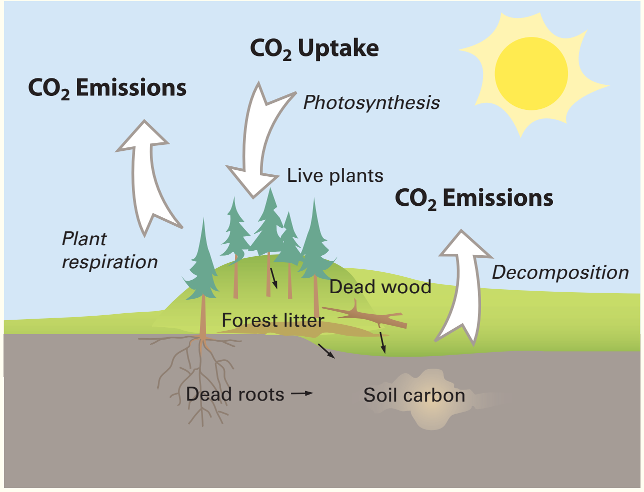


Fig. 4-4. Carbon sequestration occurs when CO_2 uptake by vegetation (via photosynthesis) is greater than CO_2 emissions from plant respiration and decomposition processes.

> **Key Mitigation Terms**
>
> *Climate change mitigation* includes actions that reduce greenhouse gas emissions or remove them from the atmosphere.
>
> *Greenhouse Gases* absorb and re-emit infrared radiation in the atmosphere. These gases can be both natural or anthropogenic, and include water vapor, carbon dioxide, nitrous oxide, methane, and ozone. In terms of influence on temperature, carbon dioxide is the most important of the anthropogenic greenhouse gases.
>
> *Biological carbon sequestration* is a natural process—driven by photosynthesis—that removes carbon dioxide from the atmosphere and stores it in plants or soils.

Terrestrial carbon sequestration (hereafter: carbon sequestration) occurs when plant uptake of CO_2 exceeds the return of CO_2 to the atmosphere through respiration and decomposition (Fig. 4-4). In natural systems such as forests, prairies, or wetlands, humans can take actions that maintain or increase carbon uptake or reduce CO_2 emissions from respiration and decomposition, both of which can increase carbon sequestration and help offset industrial CO_2 emissions. Activities that increase carbon sequestration are widely considered to be important climate change mitigation strategies.

Beyond climate change mitigation, carbon sequestration can produce other valuable benefits. Carbon sequestration strategies that establish herbaceous or woody vegetation can reduce soil erosion, improve soil and water quality, provide habitat, and increase biodiversity. In urban areas, planting trees for carbon sequestration also helps reduce energy consumption and facilitates stormwater management.

Carbon sequestration can also generate income that supports land management and contributes to the state's economy. Voluntary carbon markets allow land managers to sell carbon credits for verified increases in carbon sequestration to partially offset CO_2 emissions

Average per Acre Carbon in Forests in the U.S.

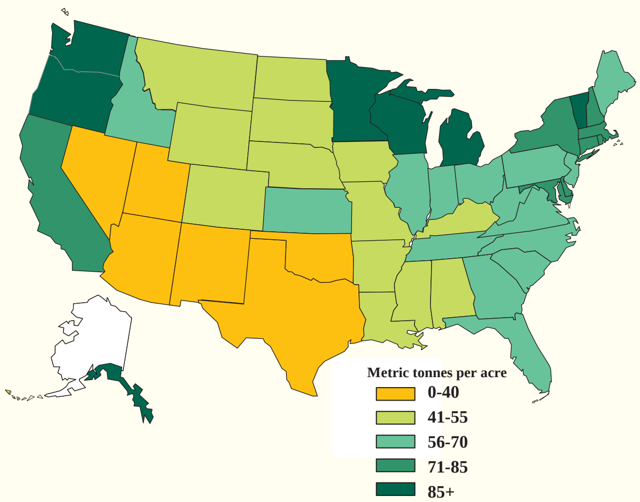


Fig. 4-5. Minnesota is one of several states with the highest per-acre carbon storage rates in the U.S. (dark green indicates >85 metric tons of stored carbon per acre) Source: U.S. Forest Service 2010.

Table 4-2. Average Carbon Accumulation and Storage in Minnesota Ecosystems and Land Types

Ecosystem or land use	Annual sequestration rate (metric tons C per acre per year)	Carbon stored (metric tons C per acre)
Forest	0.5–1.6*	99
Peatland	0.03–0.25	745
Non-peat wetlands	2.1	227–258
Grasslands	<0.5	78
Row crop agriculture	0	n/a

*Sequestration rates vary widely with age and type of forest. Sources: Roulet 2000; Jones and Donnelley 2004; Smith et al. 2005; Euliss et al. 2006.

of utilities and other large consumers of fossil fuels. Regional efforts to limit greenhouse gas emissions, such as the Western Climate Initiative in the northwestern U.S., the Midwest Greenhouse Gas Accord, and the Regional Greenhouse Gas Initiative in the northeastern U.S., have recently taken or are discussing steps to reduce emissions via emission caps and trading of carbon credits generated in offset projects. As emission caps become more common and more emitters are subject to those caps, carbon markets will expand and become more financially attractive to landowners and land managers..

Existing carbon storage and sequestration rates in Minnesota ecosystems

Minnesota's ecosystems contain vast amounts of stored carbon and vary considerably in the rate at which they sequester carbon (Table 7.2). For example, Minnesota peatlands contain about 4.25 billion metric tons of carbon (Anderson et al. 2008). Loss of the carbon contained in 1,000 acres of peatlands would release approximately 2.7 million metric tons of CO_2 to the atmosphere, increasing Minnesota's annual emissions of CO_2 by 2% above 2005 levels (Anderson et al. 2008). The same study estimated that Minnesota forests contain 1.6 billion metric tons of stored carbon, and Minnesota is one of the top states in terms of forest carbon storage per acre (Fig. 4-5). Non-peat wetlands store less carbon per acre than do peatlands, but have much higher rates of sequestration. Natural and restored wetlands store more carbon than do those that are drained and/or farmed. Grasslands and shrublands store significant amounts of carbon, primarily in soils. Agricultural soils also store significant carbon, both in surface and in deeper soil layers. Tillage and annual cropping tend to minimize the potential for increasing soil carbon stocks in agricultural soils.

When evaluating carbon management strategies, it is important to distinguish between the amount of carbon stored ("C stock") from the rate at which carbon is sequestered ("C flow"). For example, peatlands store more carbon than any other ecosystem type in Minnesota, but peatlands have much lower sequestration rates than forests or prairie pothole wetlands (Table 4-2).

Strategies for increasing carbon sequestration

Effective means of increasing carbon sequestration through management are different in each ecosystem or land type. The section below describes examples of potential strategies that may be applied to forests, wetlands, and grasslands. As with most resource decisions, costs and benefits of carbon sequestration strategies should be carefully evaluated before implementation.

In forests, managing for larger carbon pools may include:

- Afforestation (creating new forest on land not previously forested where it is ecologically reasonable to do so) creates new stocks of carbon.
- Reducing the frequency and/or intensity of wildfires may reduce the release of forest carbon to the atmosphere if doing so does not increase the likelihood of more intense, catastrophic fires.

Estimated Changes in C Sequestration Rates Upon Land Use or Cover Change in Minnesota

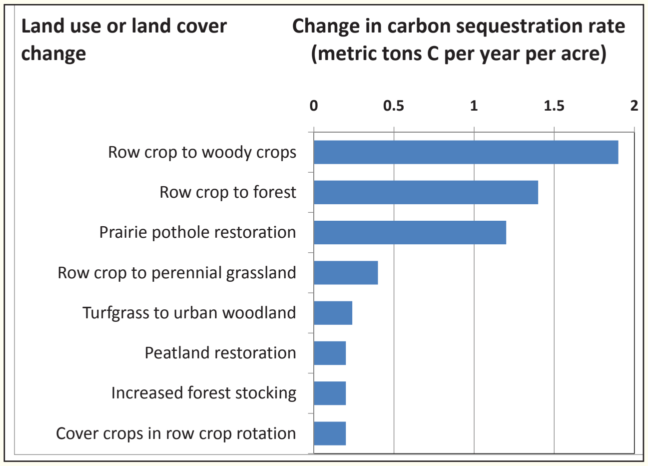


Fig. 4-6. For other land use or cover changes evaluated (row crops to pasture/hay land, conventional to conservation tillage, and low diversity to high diversity grassland) the estimated carbon sequestration rate was less than 0.2 metric tons C per year per acre. See original source for error bars and more detail (Anderson et al. 2008).

- Increasing the proportion of wood harvested and used for long-lived wood products (e.g., furniture instead of paper) lengthens the period that the carbon contained in wood stays out of the atmosphere.
- Increasing the rate at which trees grow allows carbon to accumulate more quickly.
- Preparing sites for planting or seeding using methods that minimize soil disturbance minimizes the release of soil carbon to the atmosphere.
- Lengthening rotations (the time between establishment of new forests and final harvest) keeps carbon on the landscape longer.
- Increasing the stocking of trees on lands that are not fully stocked puts more carbon into existing forests.

In peatlands and other wetlands, managing for larger carbon pools may include:

- Restoring the hydrology of drained and partially drained wetlands increases the rate at which carbon is sequestered and prevents loss of stored carbon via decomposition.
- Suppressing peat fires prevents the release of stored carbon to the atmosphere.
- Increasing the stocking of trees on peatlands, where it is ecologically reasonable to do so, increases the amount of carbon that can be stored there without compromising the carbon stored in peat.

In grasslands, managing for larger carbon pools may include:

- Adjusting the level of grazing by cattle can promote root growth and carbon accumulation in soils.
- Increasing the diversity of plant species by including perennials with extensive root systems increases carbon storage in soils.
- Minimizing soil disturbances reduces the amount of carbon released to the atmosphere.

Potential problems with increasing carbon sequestration

Land managers in Minnesota manage for multiple benefits simultaneously. Forest managers, for example, manage for sustainable yields of timber, wildlife habitat, viable populations of game and nongame species, and improved water quality. Because not all possible management objectives can be met in every location, managers set priorities and acknowledge that trade-offs among management objectives may be necessary. Adding mitigation of climate change via increased carbon sequestration to the list of management objectives will increase the likelihood that management objectives will conflict. A thorough evaluation of the compatibility of carbon sequestration and other management objectives will help guide management decisions so that we sustain valued ecosystem services while increasing the role of ecosystems in mitigating climate change (D'Amato et al. 2011).

Mitigating climate change via carbon sequestration will reduce, but not eliminate, the need to adapt to climate change. Many mitigation strategies likely will help ecosystems become more resilient to changes in climate and other threats in the future. Identifying and implementing these strategies will be a high priority.

DNR and other state agency efforts

Interagency and DNR carbon sequestration teams are identifying and evaluating ways to increase carbon sequestration on state-administered lands with the intent to incorporate practices that increase carbon sequestration into management activities where doing so will not prevent reaching other management goals. General approaches that may be widely applicable include:

- Monitoring ecosystem carbon pools' response to management activities. Information derived from regular measurement of carbon would help managers adjust their practices to increase carbon sequestration.
- Seeking additional revenue to support land management activities by participating in carbon markets. Revenue generated by selling carbon credits could support a wide variety of management activities that increase carbon sequestration.

Specific projects of DNR's carbon sequestration team include:

- Partnering with ongoing research on greenhouse gas exchange in northern Minnesota peatlands.
- Helping to develop carbon accounting protocols via the North American Forest Carbon Standard Committee and the Midwest Greenhouse Gas Accord. In both of these efforts we seek carbon accounting protocols that are appropriate to forests and their management in Minnesota and that encourage participation by a wide range of forest-land owners.
- Developing tools for evaluating the effects of management on carbon pools and fact sheets for communicating about land management and carbon sequestration. The tools will include forest growth and yield models that track carbon pools, and methods to estimate carbon amounts from standard forest inventories.
- Using forest growth models to compare carbon and biodiversity benefits of silvicultural treatments . For example, DNR and The Nature Conservancy are using the Forest Vegetation Simulator to compare silvicultural treatments in the Manitou Landscape.

Bioenergy and Conservation-based Energy Strategies

Bioenergy: a national priority

In the past decade, rising energy prices, increasing recognition of the impacts of carbon dioxide emissions, and national security concerns have led to dramatic expansion of renewable energy resources. Current national policy focuses most intensely on offsetting imported oil resource with biofuels. The 2005 Energy Bill established a nationwide renewable fuels standard (RFS) calling for 7.5 billion gallons of ethanol and biodiesel. In 2007, Congress dramatically expanded the RFS to 36 billion gallons to be fully implemented by 2022. The RFS allows 15 billion gallons of corn ethanol and requires 5 billion gallons of "advanced biofuels" and 16 billion gallons of cellulosic biofuels . The target is to displace 30% of petroleum-based motor fuels nationally. At the same time, 35 states, including Minnesota, have enacted renewable electricity standards or goals that seek to shift power generation away from coal and natural gas toward wind, solar and biomass.

Expanded bioenergy utilization can play an important role in Minnesota's energy system. Biomass has potential to contribute to a wide range of energy markets for which other renewable energy resources are not suitable. For example, biomass can be used for industrial process heat or to produce liquid fuels where wind and solar energy cannot. However, biomass production is constrained by the productivity of forest and farm land as well as competing uses for agricultural and forest products and lands.

Fig. 4-7. Logging slash sorting prior to processing by a chipper. Photo by Anna Dirkswager.

> **Key Bioenergy Terms**
>
> *Bioenergy* is energy derived from biological resources (resources also known as biomass). *Biomass* is plant or animal material that can be burned to produce energy or to make liquid fuels or industrial chemicals. *Biofuels* are liquid fuels derived from biomass.
>
> *Conservation based-energy* is biomass collection or production explicitly focused on conservation benefits (e.g., using woody invasives for energy, managing grasslands for both biomass and bird nesting cover).

What is biomass?

Biomass, as a renewable energy source, refers to plant or animal material that can be used as fuel or for the production of industrial chemicals.

Woody Biomass: Wood from trees and brush has been a source of fuel for heating and cooking throughout human history. The forest products sector has long used byproducts from its processes as an economical source of fuel. While all parts of a tree can be used for energy, industry generally considers biomass to be low-value fiber (logging slash, land-clearing debris, rotten wood, etc.). Based on an internal DNR estimate, woody biomass could offset roughly 3% of Minnesota's fossil energy needs. This is a meaningful quantity and could be realized if incentives and policies are targeted toward strategic uses of our wood resource.

Agricultural biomass: Grain and oilseed crops are the primary agricultural sources of biomass energy. However, within the agricultural industry, "biomass" often means cellulosic plant fiber, such as crop residue, hay, or dedicated energy crops. Manure, rendered animal fats, and food and grain processing residues may also be considered biomass. Agricultural biomass can be a primary product of land management (e.g., growth of energy crops) or a by-product of another activity (e.g., residue from grain production or prairie grass grown to improve habitat). By-products of energy crops can be soil, water, carbon sequestration and habitat. The relative value of conservation benefits and biomass yield can shift depending on incentives and programs.

What is a conservation-based energy strategy?

DNR's Conservation Agenda identifies "conservation-based energy" as a way to meet conservation goals while producing renewable energy. Simply put, conservation-based energy sources are biomass sources whose production provides natural resource benefits. Conservation activities such as haying to maintain grasslands , removing invasive plant species, harvesting trees to maintain young-forest habitat, and thinning forests to reduce fuel loads or enhance tree growth can produce renewable energy biomass. Dedicated energy crops can provide significant conservation benefits even if conservation or habitat management is not the primary goal. Production of perennial energy crops, either woody or herbaceous, represents a tremendous opportunity to enhance soil and water conservation on agricultural lands.

Fig. 4-8. Baling prairie grass on Giese Waterfowl Production Area in west-central Minnesota. DNR photo by Jason Strege.

Bioenergy: a range of products and markets

Energy can be divided into roughly three equal market segments: transportation fuels, electric power, and thermal energy.

The term biofuels generally refers to biomass-based transportation fuels. First-generation biofuels, primarily corn ethanol and soydiesel, currently dominate the biofuels industry. Second-generation biofuels based on alternative fuel chemistry (butanol and hydrocarbon fuels) or feedstocks (lignocellulosic) are emerging commercial products. Third-generation biofuels derived from algae have not been produced at commercial scale.

Transportation fuels generally tend to capture the greatest share of public attention. This is because they are almost exclusively derived from oil. Oil is the focus of national security concerns, is the largest source of energy in the U.S. (and global economy), and is relatively more polluting than natural gas. Also, because of the way petroleum products are purchased and used – through regular stops at the gas station to purchase a tangible product that gets used up—oil is the most visible energy resource to American consumers.

Yet, some biomass resources may be best suited for use in other energy markets such as heating fuel.

DNR's interest in bioenergy

DNR is interested in bioenergy for three main reasons: to mitigate climate change, as a conservation tool, and as an economic opportunity.

Climate mitigation: Reducing net carbon emissions from fossil fuels is a key element in climate-change mitigation. While comparisons can be difficult, bioenergy production and use generally results in lower carbon emissions than fossil fuels. Thoughtful use of biomass is a key strategy in reducing overall carbon emissions from the energy sector.

As a conservation tool: As bioenergy markets develop, resource managers can integrate biomass harvesting into the resource management tool kit. For example, biomass harvesting can be used to mimic the disturbance of fire or grazing on conservation lands. Costs, weather, and site conditions all constrain the use of prescribed fire or other management options on both public and private grasslands. A large market for biomass hay would help overcome these barriers to management. DNR has worked with partners to complete pilot harvesting on hundreds of acres of wildlife management areas to improve habitat conditions and study the impacts of harvesting. Similar opportunities for brushland and forest management could arise with more robust woody biomass markets.

A growing bioenergy market also represents an opportunity to encourage more conservation-oriented agricultural production. Energy crops can be grown on sensitive lands such as highly erodible lands, riparian corridors, or heavy soils that would otherwise require increased tile drainage. With proper incentives, energy crops could help production agriculture to more closely mimic native ecosystems. Without active engagement by DNR and other conservation interests, opportunities for increasing the conservation benefits of energy crops may be lost .

Economic opportunity: Developing biomass energy resources presents economic opportunities for the DNR, the state, and rural communities. The impact of the housing bust on the forest products industry has lead to significant economic losses in communities throughout northern Minnesota and dramatically reduced DNR revenues generated for the Forest Management Investment Account and School Trust Fund. Replacing lost markets with new renewable energy markets can replace much of that lost economic base for landowners (public and private), loggers and production workers. Additionally, as markets emerge and strengthen, the DNR stands to benefit from reduced management costs on public lands and thereby extend the work that can be accomplished with strained budgets.

DNR's role in biomass leadership

DNR helps set the standard for best management practices for growing and harvesting biomass. DNR contributed to the development of the nation's first forest biomass harvesting guidelines as a foundation for sustainable forest and brush biomass harvesting (Minnesota Forest Resources Council 2007). Biomass harvesting on DNR-managed lands must be consistent with natural resource management goals and must comply with the biomass harvesting guidelines.

These leadership roles put DNR is in a unique position to experiment, to support research, and to model biomass production options. For example:

- A 2007 DNR project restored overgrown prairie, oak savanna, and woodlands by removing undesirable woody vegetation and made the vegetation available for renewable energy use.
- DNR offers forest residues from timber harvesting on most timber sales for use as fuel and to reduce the risk of wildfire.
- DNR has included managed prairie harvest on approximately 700 acres of wildlife management areas since 2007 in an effort to explore the feasibility and habitat benefits of using perennial native grasses for fuel.
- DNR is providing leadership in demonstrating biomass harvest of brushlands for open-land habitat management.
- DNR will also continue to be a leader in developing, testing and refining guidelines to ensure the sustainability of biomass harvest.

DNR seeks to promote conservation of natural lands and ensure a sustainable biomass supply by advancing the development of conservation-based energy sources across the state. As state lands are only part of the biomass supply, DNR will need to work with a range of partners to promote conservation-based biomass production as part of sustainable land management. Establishing partnerships toward this end will involve participating in interagency policy forums, providing sound science on resource sustainability, and working with landowners, business and industry, conservation groups, and other stakeholders to promote and evaluate alternative approaches to biomass production systems.

Energy Efficiency

Reducing DNR's carbon footprint

In early April 2011 Governor Dayton signed two Executive Orders specifically directing state agencies, including DNR, to reduce energy use and improve sustainability of operations. These orders catalyze state leadership in energy conservation and renewable energy. Increasing energy conservation and renewable energy will help control costs, reduce greenhouse gasses, and contribute to the state's economy.

These orders reinforce DNR's energy efficiency goals in the 2009–2013 Strategic Conservation Agenda Part I and more detailed goals in DNR's new Five Year Plan for Sustainable Fleet, Facilities, and Purchasing Operations (DNR 2011). This Plan aims to reduce DNR's carbon footprint by using a combination of energy conservation, renewable energy, and waste reduction strategies. Implementing the plan will reduce DNR's annual energy spending and allow us to lead by example in mitigating climate change and enhancing the sustainability of our buildings and operations. The DNR has identified three main goals for this program:

- **Reduce DNR total energy use by 20% from 2010 to 2015.**
- **Reduce DNR greenhouse gas emissions by 25% from 2010 to 2015.**
- **Conserve natural resources through environmentally friendly purchasing, waste reduction, water conservation, and recycling.**

DNR will use six key strategies to meet these goals:

- Achieve building energy performance standards defined by the State's Sustainable Buildings 2030 program.
- Improve the energy efficiency of the Top 50 energy usage buildings.
- Improve the environmental sustainability of all DNR buildings and sites, striving for "net-zero" energy consumption and significantly reduced fresh water usage.
- Broadly implement on-site renewable energy systems at DNR locations.
- Increase fleet fuel efficiency through technology improvements and behavioral changes.
- Expand sustainable purchasing efforts by encouraging a broader set of purchasing considerations; including purchase cost, renewability, recycleability and total lifecycle costs.

Fig. 4-9. This 16.1 KW photovoltaic array is located at Lac qui Parle Wildlife Management Area headquarters. The DNR installed a total of 125 KW of renewable energy at 11 sites in 2010.

DNR Energy Profile

The Minnesota DNR manages a large portfolio of buildings, equipment, and energy transactions:

- Over 3.5 million square feet of space in 2,800 buildings ranging in size from 120,000 sq ft to 12 sq ft.
- Over 2,600 vehicles and thousands of other fuel consuming devices like outboard motors, chain saws, generators, etc.
- Hundreds of points of energy consumption not associated with buildings like remote security lights and dike pumps.
- Over 67,000 fleet fuel card transactions and 12,000 utility energy bills per year.

DNR has made a major commitment to accurately measuring, managing and reporting its energy consumption. In 2009 DNR joined The Climate Registry and began to publicly report its greenhouse gas emissions. The Climate Registry establishes consistent, transparent standards throughout North America for businesses and governments to calculate, verify and publicly report their carbon footprints in a single, unified registry. In 2010 DNR completed a two-year project to select and implement an online database and reporting system for energy usage and greenhouse gas reporting. This system, the Minnesota B3 Energy Benchmarking System, allows facility managers to track their energy consumption and compare it to similar buildings in the DNR.

Fig. 4-10 shows DNR's energy use since 2005, along with the 20% reduction target for 2015. Total energy use has been falling since 2008 and will have to decrease about 4% per year through 2015 to hit DNR's reduction target. Similarly, carbon emissions have been falling recently, and will continue to fall as DNR reduces its appetite for energy (Fig. 4-11).

DNR's energy spending in CY 2010 was $5.6 million. Hitting DNR's energy reduction targets would save $3.5 million over the next 5 years, while avoiding 16,200 metric tons of carbon emissions.

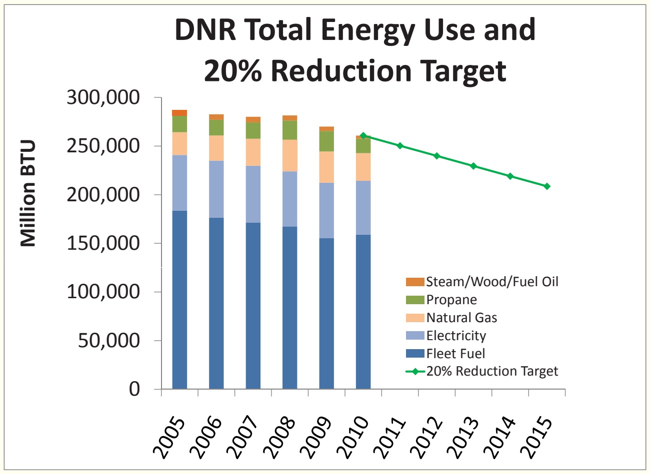


Fig. 4-10. DNR's total energy use and 20% reduction target for 2015.

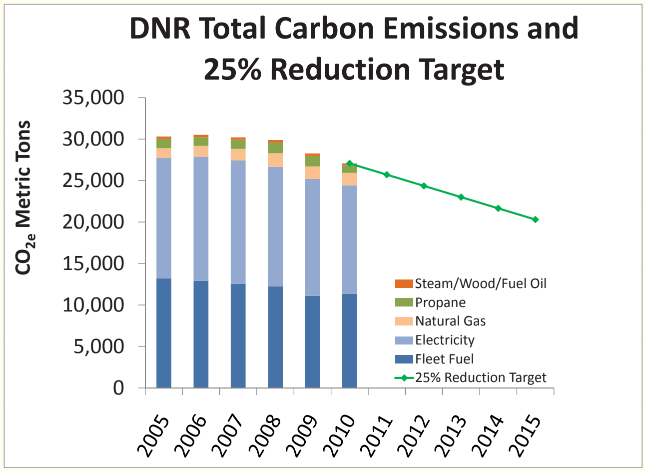


Fig. 4-11. DNR's total carbon emissions and 25% reduction target for 2015.

A Framework for Decision Making

Framework Overview

Part I of this report gave science background on climate and energy trends and their impacts on natural resources. **Part II, Section 1–2** described DNR's ongoing and proposed adaptation and mitigation responses to these trends. This section describes a decision framework that DNR will use to continually improve and integrate climate and renewable energy strategies over time as we learn more.

An Adaptive Approach

Implementing effective management responses to climate and renewable energy trends will require an adaptive management approach that tailors strategies to specific settings and refines them as we learn more. DNR will use an adaptive framework that integrates assessments, planning and decision support, management response, and monitoring (Fig. 5-1).

The goal is effective **Management Responses** that address climate change and energy challenges in ways that maintain or restore resilient ecosystems and/or encourage a transition to renewable energy.

Assessments provide the necessary information to set priorities for management actions. Assessments range from brief science reviews of trends and impacts (like Part I of this report) to more detailed climate change assessments. These more detailed assessments include "vulnerability assessments" that identify species and habitats that are most vulnerable to climate change (p. 60), "mitigation assessments" that identify the highest leverage mitigation options (p. 61), and "social assessments" that identify public and staff knowledge and attitudes about climate change to help us identify information and training needs (p. 62–64).

Planning and Decision Support activities (p. 65) help staff make day-to-day and long-term decisions on management actions, monitoring activities, and assessment activities. Climate change and renewable energy strategies will need to be integrated into natural resource plans at multiple spatial and temporal scales, including statewide strategic plans, landscape and watershed plans, management unit plans, annual work plans, and site-level plans. To implement these plans in an "climate savvy" manner, DNR will need to provide a variety of decision-support and information products, from guidance documents to training workshops.

DNR's Climate Change and Renewable Energy Decision Framework

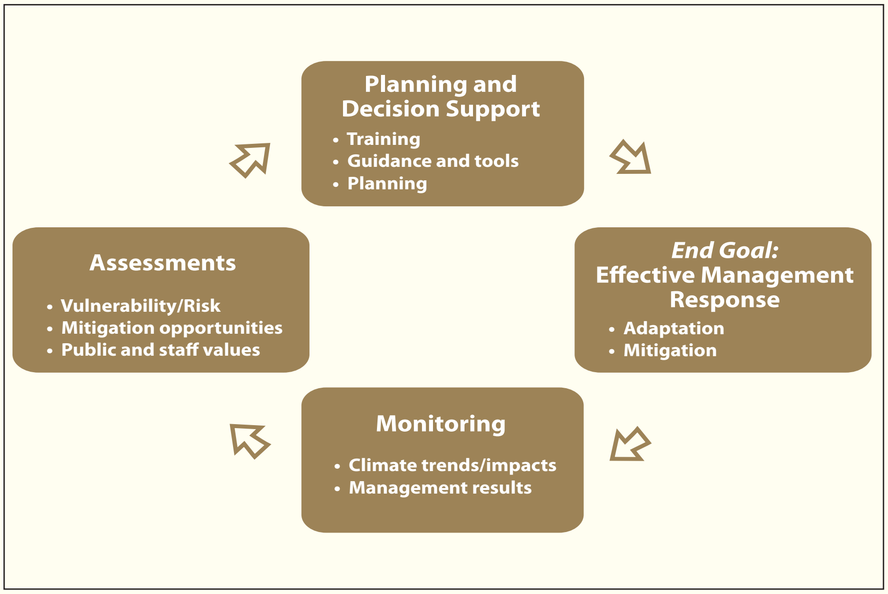


Fig. 5-1. DNR's Climate Change and Renewable Energy Decision Framework aims to improve management decisions over time as we learn more.

Monitoring (p. 66–68) tracks trends in climate and energy use, climate impacts on natural resources, and effectiveness of management actions aimed at addressing those impacts. Results from monitoring feed back into future assessments and management decisions so course corrections can be made if conditions change or if management actions are not effective.

Assessments

This section describes three types of assessments needed to understand climate change and renewable energy issues as a foundation for prioritizing actions:

- Vulnerability assessments,
- mitigation assessments, and
- social assessments.

Vulnerability Assessments

In the context of natural resources, DNR defines climate change vulnerability as the degree to which an ecosystem, resource, or species is susceptible to and unable to cope with the adverse effects of climate change (adapted from IPCC 2007b, Fussel and Klein 2006). System or species vulnerability is a function of:

- *exposure* to climate change (i.e., the magnitude of the changes experienced)
- *sensitivity* to these changes
- presence of non-climate *stressors* (existing threats)
- *capacity to adapt* to climate change and associated non-climate stressors (Figure 5-1).

Vulnerability assessments provide a starting point for prioritizing adaptation and mitigation policies, planning, and management. They can provide context to a variety of decision processes, such as setting long-term targets for mitigation, identifying highly vulnerable systems or species to help prioritize resources, and developing adaptation measures (Fussel and Klein 2006).

To build a foundation for addressing climate-change impacts in the state's conservation strategies, DNR will assess system and species-level climate vulnerability in 2011. The assessment will help the DNR meet the objectives identified in our overall mission and those outlined in specific conservation planning efforts such as the state wildlife action plan and sustainable forest resource management plans.

DNR will assess climate vulnerability using a two-tiered, overlapping process. A vulnerability assessment coordinator will convene panels of internal and external experts charged with producing reports on climate vulnerability of major ecosystems in Minnesota. The panels will also describe uncertainties involved in predicting climate vulnerability. Concurrently, DNR

Vulnerability Assessment Framework

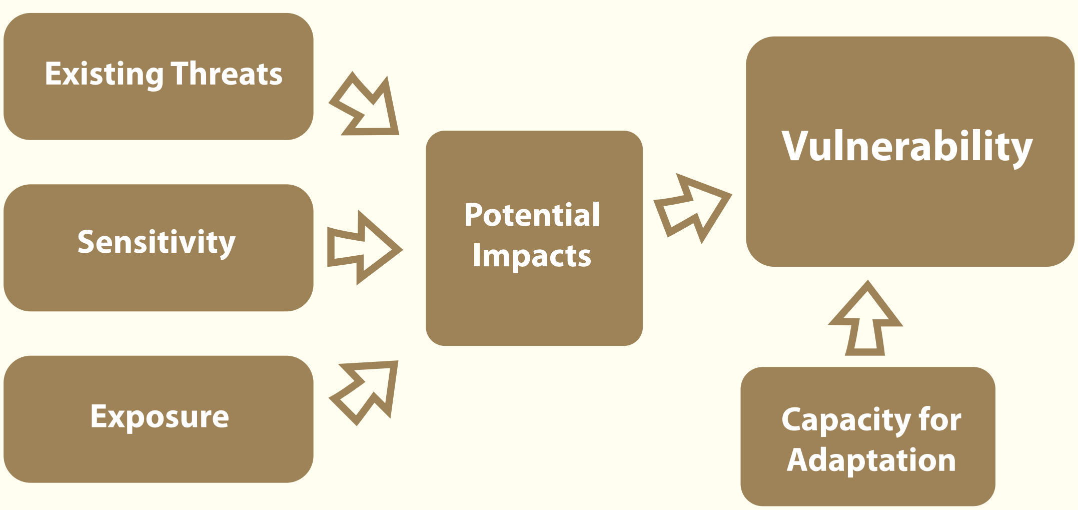


Fig. 5-1. Vulnerability Assessment Framework. Vulnerability of a system (or species) to climate change is a function of exposure to climate change (amount of change occurring), the sensitivity of the system to those changes, the presence of non-climate stressors, and the capacity of the species or system to adapt to climate changes and concurrent non-climate stressors.

will implement a species-level vulnerability assessment beginning with species identified in the state wildlife action plan and adding priority species as funding becomes available. To conduct the species-level vulnerability assessment, DNR will use NatureServe's vulnerability assessment tool. This tool produces an overall vulnerability rank and a list of factors that contribute to species vulnerability. DNR will also collaborate with other organizations conducting vulnerability assessments, such as the U.S. Forest Service. These vulnerability assessments will help managers to set conservation goals, develop management plans, and develop resilience strategies where appropriate.

Mitigation Assessments

In addition to assessing vulnerability to climate change, it is important to assess opportunities for climate change mitigation—those actions that reduce greenhouse gas emissions or remove them from the atmosphere after they have been emitted. The Minnesota Climate Change Advisory Group (MCCAG) conducted the first statewide mitigation assessment (Minnesota Climate Change Advisory Group 2008). Their recommendations included changes in land, waters, facilities, and fleet management that reduce energy consumption and increase carbon sequestration. Their recommendations were preliminary and based on information that summarized emission reduction and sequestration potentials at a state-wide level. DNR now needs more detailed assessments of the potential for mitigating climate change via its land, waters, facilities, and fleet management activities.

For Land & Waters Management, a primary focus of the DNR's mitigation assessments will be to answer the following questions:

- How much of the state's current and future greenhouse gas emissions can be offset by carbon sequestration in ecosystems, in materials derived from ecosystems (e.g., wood products) and by substituting plant material for fossil fuels?
- What are the benefits and costs of changing management actions to increase carbon sequestration?
- What ecosystem services and products may be affected by increasing efforts to sequester carbon?
- What is the role of fire and other natural disturbances in Minnesota ecosystems with respect to carbon sequestration?
- Can carbon estimation methods be cost-effectively incorporated into land management information systems to provide information that is useful in deciding what management actions are appropriate?

For Facilities and Fleet Management, DNR has thoroughly assessed our options for reducing energy consumption. DNR's Sustainability Plan, in preparation by the Management Resources Bureau, assesses the potential for reducing greenhouse gas emissions by reducing the DNR's fossil fuel consumption, increasing the proportion of energy that comes from renewable sources, purchasing products that consume less energy during production, reducing waste, conserving water, and recycling used materials. The Sustainability Plan sets ambitious goals and strategies, consistent with the Governor's Operational Order 11-13, for reducing DNR's carbon footprint. Ongoing monitoring of energy consumption will help direct efforts to reduce energy consumption in buildings and vehicles and help target where renewable energy generation is most effective.

Social Assessments

Adaptive management and stakeholder involvement

DNR's adaptive approach to anticipate and respond to climate impacts on natural resources provides a structure for addressing not only biological and ecological challenges but also social and economic considerations (Fig. 5-1). A key feature of adaptive management is the flexible decision making that can be adjusted as outcomes from management actions and other events become better understood (Williams et al. 2007). Critical to successful adaptive management is stakeholder involvement, especially for identifying objectives and management actions.

Stakeholder involvement—social assessments and public participation

Effectively managing the increasing and often conflicting human demands on natural resources requires understanding public values and attitudes as well as the biological and ecological aspects of an issue. Natural resource managers will benefit from understanding public and stakeholder knowledge, values, and attitudes about climate impacts and adaptation strategies. Human dimensions research focuses on beliefs, values, attitudes, behaviors, and socioeconomic and demographic characteristics of user groups with emphasis on incorporating such information into resource management decisions (Gigliotti and Decker 1992), and contributes to successful adaptive management. Formal social assessments for climate change adaptation may include scientifically designed focus groups and telephone or mail surveys. Public input and participation in climate adaptation planning and projects will vary depending on the objectives or potential public impact.

National public survey on climate change

A 2008 national survey of 2,164 American adults characterized the public's climate change beliefs and attitudes (Leiserowtiz et al 2009). Subsequent analysis found six categories of response to climate change (see Fig. 5-3; Maibach et al. 2010). The "Alarmed" group (18%) is convinced of the reality and seriousness of climate change and is taking action to address it. The "Concerned" group (33%) is convinced that warming is happening and is a problem but has not initiated any personal responses. Three groups are not actively engaged—the "Cautious" (19%), the "Disengaged" (12%), and the "Doubtful" (11%). The "Dismissive" group (7%) is sure that climate change is not happening and actively opposes national efforts to reduce greenhouse gas emissions.

National surveys in January and June 2010 indicate a decrease in the belief that global warming is happening (Leiserwitz et al 2010). However, belief in harmful impacts on plant and animal species has changed little.

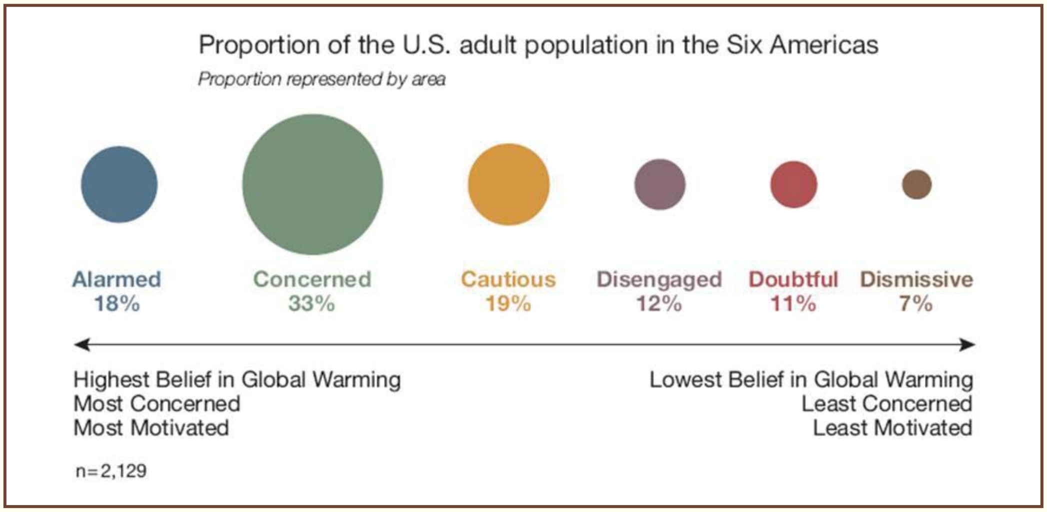


Fig. 5-3. Proportions of the U.S. adult population with different levels of belief and concern about global warming. Source: Maibach et al. 2010.

Minnesota general public survey—2010

To begin to improve our understanding of the general public's knowledge and perceptions about climate change, DNR added three questions to the annual telephone survey of Minnesota residents conducted by the Minnesota Center for Survey Research in October 2010. Sixty percent of respondents (N = 805) think that climate change is happening, 17% think that it is not happening, and 22% are not sure. For those who think climate change is happening, 74% are extremely or very sure and 26% are somewhat sure. For those who think climate change is not happening, 69% are extremely or very sure and 31% are somewhat sure.

Respondents were asked how vulnerable Minnesota is to impacts from climate change compared to the rest of the country. Fifty-seven percent of respondents think that Minnesota is equally vulnerable to climate change as the rest of the country. Thirty-three percent think Minnesota is less vulnerable, while 10% think Minnesota is more vulnerable. Respondents were also asked about climate change impacts in Minnesota over the next 50 years (Table 5-1). A majority of respondents thought that severe weather events, severe heat waves, insect outbreaks, and fish and wildlife diseases would become more frequent with climate change.

The results from the 2010 survey begin to describe the knowledge and perceptions of Minnesota citizens regarding climate change impacts. Additional information is needed to effectively adapt programs and communicate with stakeholders about current and future challenges for managing Minnesota's valuable natural resources.

To meet this need, the DNR is currently conducting a pilot study of the general public in northeastern Minnesota. The purpose of the survey is to better understand values, attitudes, behaviors, and knowledge regarding climate and potential impacts on natural resources, ecosystems, and public health in the region. Findings from this survey will inform policies, programs, and communications with the public as agencies develop and implement strategies for adapting to climate change. The study will consist of five focus groups and a general population survey. Results are anticipated to be available February, 2012. Upon completion of the pilot study, the DNR plans to expand the study to the rest of the state.

Table 5-1. Minnesota Public Expectations for Climate Change Impacts Over the Next Fifty Years.

Climate change impact	Percent of respondents who believe climate change will cause the following changes in frequency		
	More frequent (%)	Less frequent (%)	No Difference (%)
Droughts and water shortages	38	9	53
Famines and food shortages	39	6	54
Fish and wildlife diseases	52	4	44
Floods	48	6	46
Forest fires	41	6	52
Insect outbreaks	49	5	46
Invasive plant or animal species	41	6	53
Severe heat waves	52	3	45
Severe weather events	56	1	42

DNR staff survey—2010

In September 2010 the DNR conducted a department-wide survey of employees regarding climate change. Questionnaire sections included climate change in Minnesota, DNR actions toward climate change, obstacles towards applying climate change strategies, personal perceptions of climate change, information and training needs, and demographics. The questionnaire was distributed to a sample of 638 DNR employees; 67% completed the survey. Highlights of the survey include:

- Seventy-four percent of respondents are somewhat to extremely sure that climate change is happening, while 8% are somewhat to extremely sure that climate change is not happening. Eighteen percent are not sure if climate change is happening.
- Most respondents think Minnesota is either more vulnerable (29.0%) or equally vulnerable (37.9%) to impacts of climate change than the rest of the country.
- Respondents are evenly split about whether their position has a role to play in addressing climate change (Fig. 6-3).

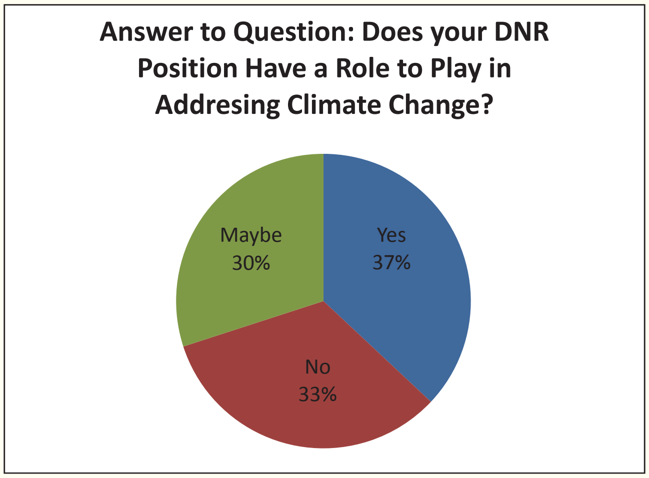


Fig. 5-4. Minnesota DNR Employee responses to survey question about their position's role in addressing climate change.

- About one-third of respondents said they are involved in climate-change mitigation activities. Of these respondents, about one-third said they take actions to reduce DNR greenhouse gas emissions (e.g., turning computer off, driving less). Other common strategies included forest management practices, public education, and outreach and private lands conservation assistance.
- About half of respondents indicated they are currently involved in climate-change adaptation activities. The most common adaptation strategies noted were managing invasive species, monitoring natural resources, and enhancing and restoring native habitats and species.
- A majority of respondents said that the greatest obstacle in applying climate change strategies is insufficient funding. Other important obstacles included "insufficient knowledge/don't know what to do," insufficient labor/staff, insufficient direction from department leadership, and insufficient time.
- To learn more about climate change, respondents overwhelmingly prefer tangible in-person training, especially through hands-on training, workshops, and conferences.

Planning and Decision Support

The complexity and uncertainty associated with climate change impacts can be challenging for natural resource managers. It can be difficult to know if, when, and how to alter management in the face of climate change. Fortunately, there are many emerging materials to help natural resource managers incorporate information on climate change into their work.

The Planning and Decision component of the Climate Change and Renewable Energy Decision Framework (p. 59) uses planning, tools, guidance, training, and information from assessments to help natural resource managers and decision makers make climate-savvy decisions. Ultimately, these decisions should foster resilient natural lands and waters and provide a diversity of ecological, economic, and social benefits in the face of climate change and other stressors. To accomplish this, planning and decision support should facilitate the flow of information, tools, and other assistance. It should also ensure that staff members have the training to incorporate climate change considerations into their decision making, and leverage lessons learned from strategies and approaches developed at the field, regional, and department levels.

Training

Staff training on climate change impacts, renewable energy, and tools for managing natural resources in the face of climate change will be paramount. In the staff survey of climate-change knowledge and attitudes (Minnesota DNR 2010b), staff ranked "insufficient knowledge/don't know what to do" as their second greatest obstacle to applying climate change strategies. Addressing this obstacle is a priority next step for successfully implementing and adapting climate change strategies.

Department Guidance

This *Climate Change and Renewable Energy: Management Foundations* document will be an important resource for developing more specific operational guidance that will be developed in future documents, training efforts, plans, and policies. Because the issue is both new and complex, DNR does not yet know how specific and prescriptive this guidance will be. We do know that any guidance should:

- foster holistic, systems thinking
- foster innovative, flexible approaches
- help DNR staff and stakeholders understand climate change impacts and explore possible solutions
- provide DNR staff with support to set and achieve natural resource goals in the face of uncertainty.

Tools

Scientists and managers have developed or are developing numerous decision-support tools that will be helpful for making climate change and renewable energy decisions. These range from web-based climate data tools such as the "Climate Wizard" (Girvetz et al. 2009), to vulnerability assessment tools (Young et al. 2011), to structured decision-making frameworks (Ohlson et al. 2005, Lyons et al. 2008).

For a list of tools see: cakex.org/tools/all.

Planning

DNR is just beginning to incorporate an understanding of climate change impacts into management plans such as Subsection Forest Resource Management Plans (SFRMPs), state park management plans, and ecosystem and species management plans. As we complete vulnerability, mitigation and social assessments, provide more training opportunities for staff, develop more specific guidance on climate change and renewable energy, and test existing and emerging tools, it will become more clear how to integrate climate change information into plans and planning at multiple scales. Undoubtedly, planning teams will develop a rich body of lessons learned that the department can use to improve planning and implementation of climate and renewable energy strategies. We will also draw on lessons learned from partner efforts in Minnesota and beyond (for emerging case studies see the "Climate Adaptation Knowledge Exchange" (cakex.org).

Monitoring

Climate change has raised awareness about the need to monitor the status of natural resources because it is causing many ecological changes and is introducing additional uncertainty to conservation decisions. The desire to monitor, however, will always exceed financial resources available for monitoring. It is imperative, therefore, to carefully identify and prioritize monitoring needs based on the potential impact on future management decisions. In this section the terms "monitoring" and "research" are used interchangeably to refer to the process of collecting observational data following a statistically valid sampling design to gain information about a system of interest.

Monitoring should address explicit objectives. It is important that the objectives be identified in the context of how the data will be used once they are collected. Two useful classes of monitoring objectives are scientific objectives and management objectives (Yoccoz et al. 2001). To make good conservation decisions we need to understand how natural systems function; we improve that understanding by collecting data to address scientific objectives. Good conservation decisions also require knowledge of the current state of a system and how it responds to management actions, which we can acquire through monitoring to address management objectives.

Improving Understanding of System Behavior

The forces of climate change are slow compared with stressors related to other human disturbances, such as landscape clearing for urban development. Consequently, the effects of climate change will likely play out over decades with a slow shift of baseline conditions (Magnuson 1990). A more variable climate will have more variable acute and chronic consequences for habitats and species, clouding our understanding of which changes are caused mostly by climate and which are caused mostly by other factors that are more easily managed. Further, stressors from climate and other sources are synergistic, and can conspire to wear away natural resilience mechanisms and facilitate shifts to novel, permanently impaired ecosystems (Carpenter et al. 1999; Hobbs et al. 2006).

To make wise natural resource management and policy decisions in this context, managers and policy makers must have a solid understanding of the basic structure and function of the systems they manage, and generate hypotheses about how various human stressors (and management response to those stressors) will affect key processes, habitats, and populations. These hypotheses will guide data collection and decision making. A conceptual model detailing important system components, species interactions, energy flows, and potential influences of stressors should be used to guide decisions about what to monitor and how often (Niemeijer and de Groot 2008; Lindenmeyer and Likens 2009; Box 11). Likewise, conceptual models of ecosystems facilitate more clear interpretation of findings and thus lead to more informed management decisions.

Informing Specific Management Decisions

If the goal of a monitoring program is to address management objectives, a specific management decision (i.e., choice among alternative management actions) needs to be identified and analyzed. In other words, to define management objectives, start with a decision and the objectives related to that decision. Only through analysis of a decision is it possible to identify and prioritize the important considerations, the thresholds at which the choice is likely to change, and the uncertainties that affect the decision outcomes (e.g., Keeney 2009; Keeney and Raiffa 1976).

A monitoring program can be directly linked to a management decision by providing information for: (1) evaluating the state of a system when decisions about management actions depend on the state of the system (e.g., wildlife population size), (2) evaluating how well management actions achieve objectives, and (3) learning about the dynamics of the system in a formal adaptive management framework (Williams et al. 2007, Lyons et al. 2008).

The most widely cited and perhaps longest running example of monitoring programs that are formally linked to management decisions is the adaptive harvest management program for migratory waterfowl in North America (Williams and Johnson 1995; Williams et al. 1996). Recently, however, additional similarly focused monitoring programs and formal decision frameworks have been successfully implemented (e.g., U.S. Department of the Interior 2010).

Other Important Considerations

Determining what to monitor and how to monitor are important decisions as well and should be based on the monitoring objectives. Many authors have reviewed these and other decisions related to designing and implementing a monitoring program. The following recommendations are paraphrased from Nichols and Williams (2006), Lovett et al. (2007), Magner and Brooks (2007), and Lindenmayer and Likens (2010):

- Programs are designed around well-formulated and tractable scientific or management questions (i.e., objectives) that are addressed at the appropriate spatial and temporal scales.
- The design is based on a conceptual model describing basic system structure and function and influential system drivers.
- Programs are frequently reevaluated and adjusted as necessary to remain relevant to current needs and possible future ones while protecting the continuity of informative long-term data sets.
- Measurements are chosen carefully and focused on the monitoring objectives.
- Quality assurance and quality control procedures for data collection and storage are established and enforced.
- Data sets are accessible and understandable to current and future partners, constituents, managers, and policy makers.
- Indicators are determined in consultation with partners, constituents, managers, and policy makers, and results are disseminated frequently to them.
- Research programs are integrated with long-term monitoring so special investigations can use long-term data sets.
- Collaborations are built to leverage human and financial resources and to cooperate on mutually shared interests for ecosystems.
- Programs have ongoing sources of funding.
- Strong and enduring leadership supports long-term monitoring programs and prioritizes their viability in lean budget years.

Box 11. Using Conceptual Models to Improve Monitoring

To better understand the implications of major ecological drivers of change on lake habitats and fish populations, the Section of Fisheries designed and implemented a collaborative lake monitoring program (Sustaining Lakes in Changing Environment: http://www.dnr.state.mn.us/fisheries/slice/index.html). This effort involved using conceptual models of lake system function to guide decisions about what to measure and how often to address current status of lake habitats and fish communities and their sensitivity to landscape and climate change (Fig 5-6.)

Although information gathered will provide a basis from which to compare effectiveness of individual lake management (i.e., how do indicators in Lake X compare with regional or statewide trends), SLICE's greatest relevance and impact will be to inform the extent (both spatial and temporal) that lake habitats and fish populations are changing as a result of human stressors and whether regional or statewide lake management policies are maintaining or improving functioning lake ecosystems.

Figure 5-6.

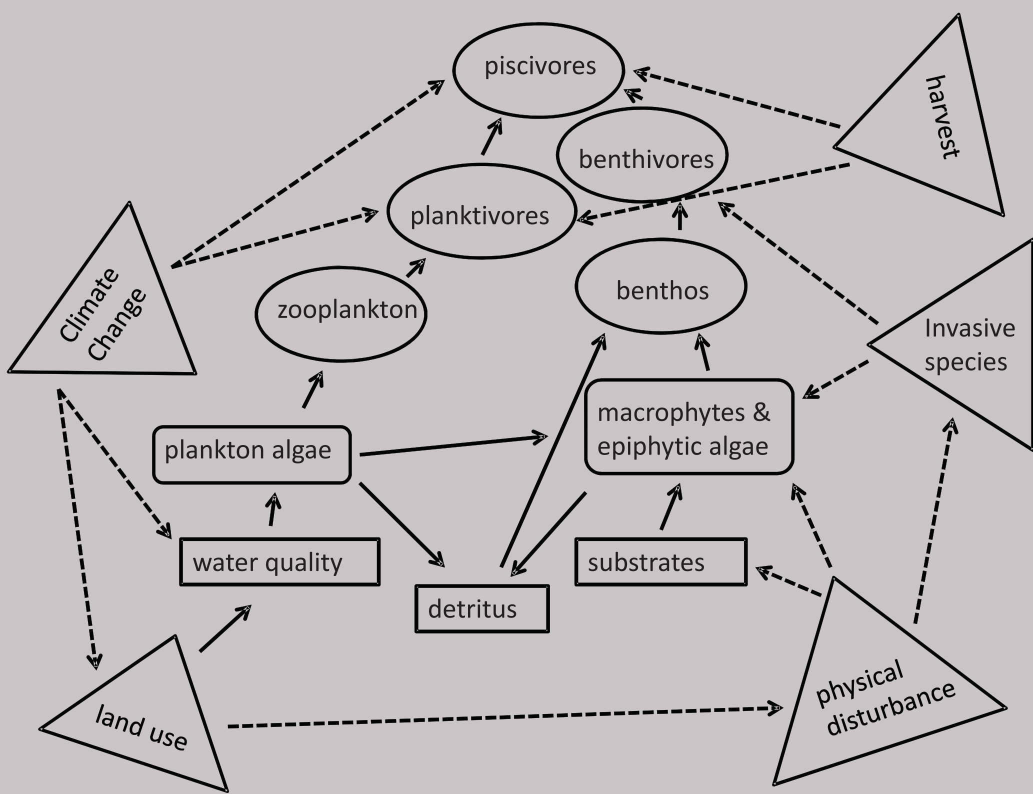


Fig. 5-6. Conceptual model documenting major lake ecosystem components (boxes), interactions and energy flows (arrows). Triangles are potential stressors, square boxes are physical components, rounded boxes are flora, and ovals are biota. Lines represent effect pathways with dashed lines representing potential stressor pathways (R.D. Valley, unpublished Dingell-Johnson Federal progress report F-26-R-36 Study 605 2009).

Appendix

Next Steps

Following distribution of this document, CREST work teams will continue working on FY2012 priorities and will engage in a series of discussions with department staff to define longer-term priorities and needs. FY 2012 priorities include:

Adaptation Team:

- Assist Ecological and Water Resources in Completing "Vulnerability Assessments" (VAs) for at least three major ecosystem types in Minnesota. Help acquire resources for additional Vulnerability Assessments (e.g. for tree species and endangered and threatened plant species).
- Develop a menu of adaptation strategies, stratified by level of uncertainty and risk. Low-risk strategies are robust to different climate outcomes. High-risk strategies need further evaluation to determine applicability.
- Disseminate results of a department-wide survey of staff knowledge and attitudes about climate change and climate change response strategies to help refine and target training and education efforts.

Biofuels Team:

- Complete a GIS analysis of constraints affecting potential woody biomass availability.
- Finalize and distribute a biofuels guidance document and engage staff in addressing biomass harvesting relative to other DNR goals.
- Document lessons learned and provide summaries of ongoing biofuels demonstration and assessment projects.

Energy Efficiency Team:

- Launch Site Sustainability Team pilot projects to identify and implement site-specific energy and sustainability improvements.
- Complete pilot of technology for trip planning and vehicle sharing to reduce fleet fuel consumption.
- Increase number of available sustainable product options and train buyers on green purchasing policy.

Carbon Sequestration Team:

- Develop tools for managing carbon in the state's ecosystems more effectively and to prepare the department to participate in future carbon markets.
- Participate in and influence forest carbon accounting protocol development.
- Conduct pilot projects that will test carbon sequestration strategies and accounting protocols.

Integration Team: Focus on New and Emerging Priorities

- Develop and implement a climate and renewable energy communications plan focused on internal communications.
- Disseminate this report widely throughout the department; convene discussions to share report findings and determine next steps.
- Promote and enhance partnerships with other agencies, universities, and private groups working on climate change and renewable energy issues.
- Develop funding proposals to help meet critical unmet needs.

For More Information

Go to http://intranet.dnr.state.mn.us/workgroups/crest/index.html

Glossary

Bioenery, Biomass, and Biofuel

Bioenergy is energy derived from biological resources (resources also known as biomass). Biomass is plant or animal material that can be burned to produce energy or to make liquid fuels or industrial chemicals. Biofuels are liquid fuels derived from biomass. First-generation biofuels are made from sugar, starch, vegetable oil, or animal fat using conventional technology (e.g., corn ethanol or biodiesel). Second-generation biofuels use "biomass-to-liquid" technology (e.g., cellulosic biofuels from non-food crops). Third-generation biofuels are made from algae.

Carbon Footprint

The total set of greenhouse gas (GHG) emissions produced or caused by an organization or entity.

Carbon Sequestration

There are two main types of carbon sequestration: biological and geological. Biological carbon sequestration is a natural process—driven by photosynthesis—that removes carbon dioxide from the atmosphere and stores it in plants or soils. Geologic carbon sequestration is the human-mediated process of capturing industrial CO_2 and storing it in geological formations (also known as "carbon capture and storage," or CCS). Because geological carbon sequestration is beyond the scope of DNR management activities, this report focuses on biological carbon sequestration.

Climate Change Adaptation

Actions that help human and natural systems prepare for and adjust to climate change. Examples include increasing the diameter of culverts to deal with increased precipitation and runoff, increasing species and genetic diversity in tree plantings to increase adaptability to future changes, or increasing habitat connectivity to allow species to migrate as the climate changes.

Climate Change Mitigation

Actions that reduce greenhouse gas emissions or remove them from the atmosphere. Examples include reducing energy consumption, switching to renewable fuels, or increasing acreage and volume of forests to increase carbon sequestration.

Climate Change Vulnerability

The degree to which an ecosystem, resources or species is susceptible to and unable to cope with adverse effects of climate change. Vulnerability assessments will help to prioritize adaptation and mitigation policies, planning, and management efforts.

Conservation-based Energy

Biomass collection or production explicitly focused on conservation benefits (e.g., using woody invasives for energy, managing grasslands for both biomass and bird nesting cover).

Decision support

Organized efforts to produce, disseminate, and facilitate the use of data and information in order to improve the quality and efficacy of decisions.

Greenhouse Gases

Gases that absorb and re-emit infrared radiation in the atmosphere. These gases can be both natural or anthropogenic, and include water vapor, carbon dioxide, nitrous oxide, methane, and ozone. In terms of influence on temperature, carbon dioxide is the most important of the anthropogenic greenhouse gases.

Resilience

A natural or human community's capacity to anticipate, endure, and adapt to change.

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