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MINNESOTA ENVIRONMENTAL QUALITY BOARD

Wednesday, August 20, 2014

Meeting Location: Duluth City Council Chambers
411 W. 1st Street 3rd floor
Duluth, MN 55802
1:00 p.m. – 4:00 p.m

AGENDA

I. *Adoption of Consent Agenda
Proposed Agenda for August 20, 2014 Board Meeting
July Meeting Minutes

II. Introductions

III. Chair's Report

IV. Executive Director's Report

V. Clean Energy and the Next Generation Act

VI. After the storm: Recovery efforts and rebuilding a resilient Duluth

VII. How climate change is impacting Lake Superior

VIII. The St. Louis River Area of Concern – A Great Lakes Restoration Initiative Priority Project for Minnesota

IX. Climate change in Minnesota: maple, spruce, or savanna?

X. Public comment period

XI. Board discussion

XII. Adjourn

Note: Items on the agenda are preliminary until the agenda is approved by the board.

This agenda and schedule may be made available in other formats, such as Braille, large type or audiotape, upon request. People with disabilities should contact Elizabeth Tegdesch, Board Administrator, as soon as possible to request an accommodation (e.g., sign language interpreter) to participate in these meetings.

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>> note location of this meeting <<

ANNOTATED AGENDA

General
This month's meeting will take place in the City Council Chambers at 411 West 1st Street in Duluth. The meeting will begin at 1:00 p.m. Parking is available at street meters or in several lots nearby, B & D are the closest daily lots. http://www.duluthparking.com/#!locations/c10th

I. *__Adoption of Consent Agenda__
Proposed Agenda for, August 20, 2014 Board Meeting
July Meeting Minutes

II. **Introductions**

III. **Chair's Report**

IV. **Executive Director's Report**

Materials enclosed:
- Climate communications document
- Midwest National Climate Assessment

V. **Lieutenant Governor Yvonne Prettner Solon**, Clean Energy and the Next Generation Act

VI. **Mayor Don Ness**, After the Storm: Recovery efforts and rebuilding a resilient Duluth

VII. **Presenter:** Professor Steve Colman
Large Lake Observatory, University of Minnesota Duluth

Materials enclosed: None

Issue before the Board: How climate change is impacting Lake Superior

Background: Invited briefing on the range of climate and other research being done on Lake Superior by the Large Lakes Observatory.

** Items requiring discussion may be removed from the Consent Agenda*
***Denotes a Decision Item*

Discussion: Lake Superior is more appropriately considered a sea rather than a lake. Superior contains 10 percent of the surface freshwater on earth, which makes it resistant to large-scale disturbance. The Large Lakes Observatory, a unique oceanographic institute dedicated to understanding inland seas throughout the world, is particularly well suited to study the effects of climate change on the Superior Sea. Despite its size and inertia, the Superior Sea is changing in unexpected ways and it is warming faster than anticipated. These changes have implications for global response to climate change as well as for the future of the ecosystem in Lake Superior.

VIII. **Presenter:** Nelson T. French
Lake Superior Unit Supervisor, Minnesota Pollution Control Agency

Materials enclosed:

- Great Lakes Water Quality Agreement Annex 1 – Areas of Concern
- Remedial Action Plan Summary Brochure
- Link to the St. Louis River Area of Concern web page (links to the 78 page plan and 600+ page appendix can be found on that page)
- Summary Map showing Remediation and Restoration Sites
- Opinion Editorial

Issue before the Board: The St. Louis River Area of Concern – A Great Lakes Restoration Initiative Priority Project for Minnesota

Background/Discussion: This is an informational item describing an extensive effort underway to restore the St. Louis River Area of Concern by removing nine beneficial use impairments identified in the late 1980's under provisions of the *US-Canada Great Lakes Water Quality Agreement*, *Annex 1*. From 2011 – 2013 MPCA led and coordinated with local, state (including MNDNR and WIDNR) and federal agencies and community organizations a strategic planning effort to develop the *2013 Remedial Action Plan* which identifies some 58 specific actions that must be taken to remove the 9 aforementioned impairments and meets the requirements of USEPA and the International Joint Commission. Included in these actions are several large and complex contaminated sediment remediation projects and several large and complex habitat restoration projects (see map). The plan calls for completing the remediation and restoration construction at approximately these sites by 2020 with formal "delisting" of the Area of Concern schedule for 2025 after post-construction monitoring shows acceptable system recovery. The major site actions in this plan will all require various levels of environmental review and permitting.

IX. **Presenter:** Dr. Lee E. Frelich
Director, The University of Minnesota Center for Forest Ecology

Issue before the Board: Climate change in Minnesota: maple, spruce, or savanna?

Background: Major changes in Minnesota's forests are sure to occur over the next century, in response to stresses imposed by a warming climate, reinforced by invasive species and deer grazing. Climates and ranges of native species could shift 300 or more miles to the north. Because the prairie-forest border cuts across the state from the northwest corner to the southeast corner, and many important tree species like spruce, fir, tamarack, and birch reach their southern/western range limits in the state, this shift will lead to major changes in vegetation type and wildlife habitat, the magnitude of which will be directly related to magnitude of climate change.

Discussion: Minnesota is at a unique location on the planet, where we expect a larger than average magnitude of climate change compared to the world as a whole. The state also has a lot of edges, such as the prairie-forest border, making our vegetation and remaining natural areas particularly vulnerable to climate change. By the end of the century we project that the climate of Minnesota will be that currently prevailing 300 miles to the south-south-west for a business as usual emission scenario, or about half that for a scenario with major emissions reductions. In other words, northeastern Minnesota would have a climate similar to eastern Nebraska and northern Iowa for the business as usual scenario, while the Twin Cities would have a climate like Manhattan, Kansas. If climate change mitigation is successful, then the magnitude of climate change would be smaller, but significant change is already in the pipeline due to heat-trapping gases that have already accumulated in the atmosphere.

Increasing mean temperature and increasing variability in temperature and precipitation are likely to lead to periods of extreme drought stress for forests, with with increasing episodes of dieback, insect, fire and windstorm damage in the future. Other environmental changes are likely to reinforce the effects of climate change. European earthworms in particular, exacerbate the effects of drought, reduce tree growth rates, and facilitate invasive plants such as buckthorn. Deer eating tree seedlings will also pose problems for tree persistence, and cause certain tree species to decline in abundance. Replacement of forest vegetation with grassland or savanna is likely to occur on shallow or sandy soils, while drought tolerant hardwoods like elm, bur oak and basswood could persist on deeper, finer textured soils. For a business as usual carbon emissions scenario, we can expect to lose the boreal biome by the end of the century, one of our three biomes, which houses 1/3 of all plant and animal species native to Minnesota.

Using our largest and most pristine natural area as a case study, for a business as usual scenario, forests of the BWCAW are very likely to be replaced by oak savanna. For a reduced emissions scenario, the BWCAW could have a mosaic in which small patches of the current boreal forests persist in refuge locations (bogs and north-facing hillsides), together with patches of maple and oak woodland and oak savanna. Note that many savanna species are currently located on small highly fragmented natural areas in southwestern Minnesota and adjacent Nebraska and Iowa, and are unlikely to be able to migrate to northern Minnesota on their own. All of these changes will pose major conservation and management problems.

X. Public comment period

XI. Board discussion

XII. Adjourn

MINNESOTA ENVIRONMENTAL QUALITY BOARD
MEETING MINUTES

Wednesday, July 16, 2014
MPCA Room Board Room, 520 Lafayette Road N, St. Paul

EQB Members Present: Dave Frederickson, Kristen Eide-Tollefson, Tom Landwehr, Dr. Ed Ehlinger, Katie Clark-Sieben, Julie Goehring, Brian Napstad, John Linc Stine, Sandy Rummel (Met Council)

EQB Members Absent: Mike Rothman, Erik Tomlinson, John Saxhaug

Staff Present: Will Seuffert (EQB), Kate Frantz (EQB), Megan Eischen (EQB), Caroline Magnuson (EQB), Erik Dahl (EQB), Anna Henderson (EQB), Beth Tegdesch (MPCA for EQB)

Chair Dave Frederickson called the meeting to order.

I. Adoption of Consent Agenda and Minutes

A motion to adopt the Consent Agenda and approve the June 18, 2014, meeting minutes was made and seconded.

II. Introductions

III. Chair's Report

No report.

IV. Executive Director's Report

- The next Silica Sand Rulemaking Advisory Panel Meeting is scheduled for July 24th, most of the agenda is reserved for discussion of environmental review thresholds; we will be looking at the survey sent out to our panelists and will bring the discussion back to the Board at the September meeting. This is not a decision item, just a conversation about the rule and the direction we think we will go with it.
- Update on the Minnesota Sands EIS: EQB staff have not received a payment, a signed cost agreement, or a data submittal from Minnesota Sands for the multi-site project at this time. We will provide a status update if this changes.
- The Governor's Clean Energy and Economic Development Summit is scheduled for July 17th at the U of M McNamara Center.
- The August 20th Board meeting will be in Duluth. We will be presenting the Climate Report.
- In 2013 the EQB participated in a strategic planning process facilitated by the Governors' Institute on Community Design. One recommendation that came out of that process, as well as the Environmental Congress that preceded it, was that the EQB should re-new its focus on water management coordination. In fulfillment of that priority, we have invited member agencies to present to the board their signature inter-agency water management initiatives. Staff was asked to compile an inventory of existing interagency efforts related to water management. Although silica sand, climate, and environmental review programs remain the focus of this calendar year, we want to spend some time with the Board on water management issues.
- On or around August 10th, the new EQB website will be up and running.

V. Environmental Review Internship Update

Presenters: Caroline Magnuson, EQB staff; Amy Whooley, EQB Intern

The EQB's environmental review intern presented the draft revised "Citizen's Guide to Environmental Review" documents and recommendations to help improve understanding of

environmental review for members of the public. Amy worked with the Governor's Plain Language Initiative to accomplish this. She shared examples of the "new" documents showing improved accuracy, clarity, and effectiveness, as well as making the information more user-friendly.

After completion of this project, EQB staff will finalize the documents and consider the prioritized recommendations.

VI. Overview of EQB Statutory Water Responsibilities
Presenters: Erik Cedarleaf Dahl and Kate Frantz, EQB staff

Staff presented an overview of EQB statutory responsibilities associated with water; GICD recommendations; Minnesota Water Plan summaries; and other report recommendations.

VII. Water Governance Evaluation: 2014 Update and Future Directions
Presenter: Suzanne Rhees, Floodplain & Land Use Planner, DNR, Division of Ecological and Water Resources (and Project Coordinator for Report)

Reviewed the 2014 Update of the Water Governance Evaluation (2013) and discussed potential role of EQB and other agencies going forward.

VIII. Planning for Groundwater Sustainability in the 21st Century Minnesota
Presenter: Jason Moeckel, Minnesota DNR, Division of Ecological and Water Resources

Jason gave a presentation on water use trends and groundwater management in Minnesota.

IX. One Watershed One Plan
Presenter: Melissa Lewis, Board of Water and Soil Resources

This presentation is to inform the Board about developing the One Watershed, One Plan program.

X. Update on the Implementation of the Minnesota Agricultural Water Quality Certification Program
Presenter: Matt Wohlman, Assistant Commissioner, Minnesota Department of Agriculture

The Minnesota Agricultural Water Quality Certification Program (MAWQCP) is a voluntary program designed to accelerate adoption of on-farm conservation practices that protect Minnesota's lakes and rivers. Producers who implement and maintain approved farm management practices will be certified and in turn assured that their operation meets the state's water quality goals and standards for a period of 10 years.

An update was given on the implementation of this new program.

XI. Adjourn

If you would like to hear the audio recording of the July 16, 2014, EQB Board Meeting, go to the following link: ftp://files.pca.state.mn.us/pub/EQB_Board/

Minnesota and Climate Change:
Our Tomorrow Starts Today

MINNESOTA ENVIRONMENTAL QUALITY BOARD
EQB

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CLIMATE ACTION: WHERE WE STAND

In 2007, the Minnesota legislature adopted the Next Generation Energy Act, including one of the strongest renewable energy standards in the nation.

It was a proud moment in our state's history. We joined with others around the world in recognizing that changes in our climate, caused by harmful emissions from our power plants, vehicles and industries, would dramatically alter the way we live, work and play in the future—unless we took action.

The legislation was a game changer. In carrying out the law, Minnesotans would strive for more clean, homegrown energy, like wind and solar; waste less energy; and decrease our contribution to global warming.

Included in the law is the Renewable Energy Standard, which requires us to get 25% of our power from renewable energy sources by 2025. It also sets greenhouse gas reduction goals of 15% by 2015, 30% by 2025 and 80% by 2050, as well as an annual energy savings goal of 1.5% of retail sales for electric and natural gas utilities.

Fortunately, we've made significant progress in reaching our goals. According to the Minnesota Pollution Control Agency, if emission avoidance policies and programs in the electric power sector continue at present levels through 2025, Minnesota will see a 33% reduction in expected electric power sector emissions—a credit to the state's aggressive Renewable Energy Standard, Conservation Improvement Program and repowering projects.

Even so, Minnesota will not achieve the first milestone—the 15% reduction in greenhouse gas emissions by 2015. We have work to do, and I am committed to getting Minnesota back on track.

The impact of the changes we're making—incremental and invisible as they may seem now—will dramatically shape the quality of life for our children and their children. When those generations look back on our actions, will they believe that we did enough?

They will—if we seize the modern, sustainable strategies and technologies at our fingertips to save energy, reduce our reliance on coal and oil, and create jobs that grow our economy and protect our health and environment. Our grandchildren and great-grandchildren will breathe clean air, drink clean water and enjoy Minnesota's cherished lakes, woods and prairies—just as we have in our own lifetimes. And they will know that we did what was right. For everyone.

Let's move forward together, acting from the common sense foundation we've already laid. We'll make Minnesota cleaner, healthier and vibrant for future generations.

Governor Mark Dayton

THE POWER OF CLIMATE CHANGE

In ways both plain and simple, the world's climate is changing. As is Minnesota's.

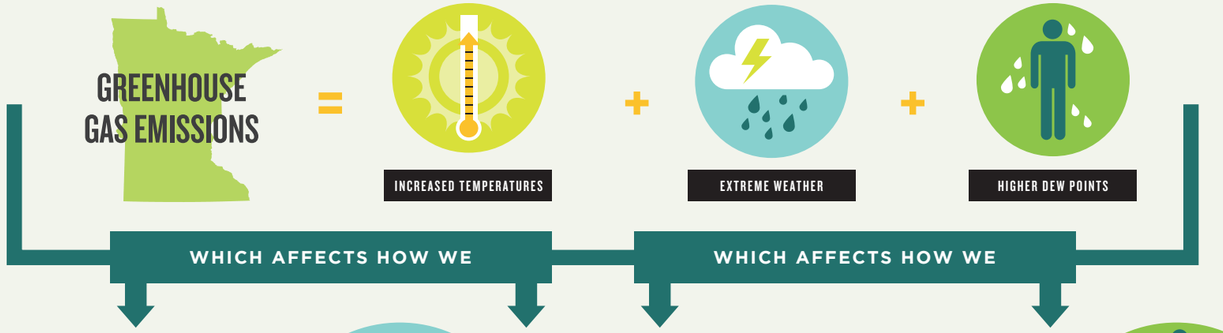
Scientists have issued their strongest position on climate change, warning that changes are happening now and are no longer a far-off concern. Moreover, problems will grow substantially worse unless greenhouse gas emissions are brought under control, particularly in the next 15 years, to forestall the worst effects of global warming.

In Minnesota, climate change has hit home, with three 1,000-year floods since 2004 and dozens more intense weather events—from hailstorms to tornadoes to droughts.

Financial impacts are just as real. **In 2013, Minnesota had some of the highest weather-related disaster claims in the country,** even topping some tornado- and hurricane-prone states. And, University of Minnesota economists estimate that **electricity generation annually causes more than $2 billion in environmental and health damages**, such as asthma aggravated by air pollutants.

Scientific predictions of extreme heat, poor air and water quality, and sweeping changes to Minnesota's wildlife and fish habitats foreshadow significant changes in the way we work, live and play.

CLIMATE CHANGE: WHAT'S AT STAKE?



WORK

Businesses Face Risks
Climate change has the power to contribute to lower gross domestic products, higher food and commodity costs, and greater financial risk.

Minnesotans may be surprised to hear that familiar companies, such as Coca-Cola and Chipotle, are already preparing for disruptions in water and ingredient sources.

Good News, Bad News for Farmers
Longer growing seasons are a blessing for farmers, but severe weather and heat-loving pests, invasive species and plant diseases could wipe out their gains. Extreme heat is another factor, which causes stress, illness and even death in livestock.

-47%

Apple production in Minnesota was as much as 47% below normal in 2012. A hard frost in April followed an unusually warm March, damaging buds. A few months later, apples suffered damage from hail and drought.

Tough Conditions for Outdoor Workers
Summer heat and poor air quality could make it difficult for construction workers, landscapers and other outdoor workers to keep cool and breathe easily.

LIVE

Heat and Smog
With more days topping 100-degrees Fahrenheit, Minnesotans could experience more days with poor air quality, causing respiratory and cardiovascular problems.

100°F

With more extreme heat comes the higher risk of heat-related illness.

Floods and Drought
Intense, local thunderstorms mean some Minnesotans will experience heavy rain and flooding, while others will face severe drought and the risk of wildfires.

Water Woes
Drought could reduce drinking water supplies. Drinking water could smell or taste bad, thanks to heat-induced algae growth. And chances of waterborne disease outbreaks increase with more flooding.

Wheezing, Sneezing
A longer allergy season is likely—and allergies may be more severe. Health officials say this can worsen asthma symptoms for vulnerable populations, such as kids and the elderly.

Food Security
Volatile weather, more heat-loving pests—and even longer growing seasons—cause swings in food production, costs, availability and nutritional value.

BUMP

Road Bumps
Increased freeze-thaw cycles in winter will degrade Minnesota's roads more quickly and increase replacement costs. More winter ice and rain (vs. snow) will make it even harder to keep roads safe. And, more summer heat means more buckled roadways.

PLAY

A Changing Forest
It is likely that iconic spruce, fir, aspen and birch trees will retreat northward, and the Boundary Waters Canoe Area (BWCA) may give way to hardwood forests.

Shorter Snowmobile, Ski and Sled Season
Minnesota might have a shorter season of snow and ice cover, resulting in fewer winter recreational opportunities.

Less Lake Fun
It may be difficult to boat, ski or swim in some lakes with excessive algae blooms or more rooted-plants plaguing lakes. Both grow due to nutrient-loading (from residential and agriculture runoff), warmer water temperatures and longer growing seasons.

More Disease-Carrying Pests
Tick- and mosquito-borne illnesses are already on the rise. Health officials say climate change may explain a geographic spread of ticks, especially in northern Minnesota.

Heads Up, Hunters and Anglers
From the North Shore to prairie country, the diversity of fish and wildlife is changing, as factors such as heat stress and flooding alter the availability of food, water and habitat.

-52%

Northeastern Minnesota's moose population has dropped 52% since 2010. Scientists have attributed some deaths to parasites and overall poor physical condition. Both may be linked to warming temperatures.

37% OF FISH ARE AT RISK

37% of all freshwater aquatic animal species, from trout in North Shore streams to walleye in Lake Pepin, could be at risk. This risk poses potential economic and cultural losses.

THE POWER OF CLIMATE CHANGE

Minnesota Meteorologists Explain Climate Change

Minnesotans love to talk about the weather. But when weather patterns change, experts encourage people to shift their conversations to climate change.

"Climate is what you expect. Weather is what you get. Climate change tilts the odds towards extreme weather, the way steroids pump up a baseball player. You can't prove any single home run was sparked by steroid use, but you did see how it increased the player's batting average."

Paul Douglas, Meteorologist

"When I see changes in data from our own backyard, I take notice."

Dr. Mark Seeley, University of Minnesota Extension Climatologist and Meteorologist

By the Numbers

For decades, Dr. Mark Seeley and other climatologists have tracked three climate trends—**rising temperatures, extreme storms and higher dew points**—driving the frequency and intensity of **extreme weather** in Minnesota.

Temperatures Are Rising

The temperature in Minnesota has increased 1°F to 2°F since the 1980s, after decades of essentially no change. The closer to the present that the trend is assessed, the greater the rate of observed increase.

Projected increases: 2°F to 6°F more by 2050 and 5°F to 10°F by 2100.

Extreme Storms

Yearly frequency of the largest storms—those with three inches or more of rainfall in a single day—have more than doubled in just over 50 years.

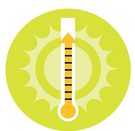
In the past decade, such dramatic rains have increased by more than 70%.

Scientists project that extreme weather events will occur more frequently.

Dew Points Are Higher

Dew point measures the air's moisture. When dew point temperatures reach 70-plus degrees Fahrenheit they are tropical. We are experiencing greater frequency of 70°F dew points. When the dew point and air temperature are high, so is the heat index, a measure of how the temperature feels with the two combined.

Minnesota had never recorded an 80°F dew point until the summer of 1966. Since then, 80°F dew points have occurred more frequently.



Seven of Minnesota's 10 warmest years occurred in the last 15 years.

Since 2004, Minnesota has had three 1,000-year flash floods.

On July 19, 2011, Moorhead was the hottest, most humid spot on Earth. Its 88°F dew point and 134°F heat index eclipsed the Amazon Jungle—the only other place in the Western Hemisphere with a dew point in the 80s.

How We Cause Climate Change

Ninety-seven percent of scientists—including the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA)—agree that humans are causing climate change.

"Changes in temperature, precipitation patterns, snow and ice cover, and sea level have naturally happened throughout history," Dr. Mark Seeley said. "What's different now is how quickly changes are happening, given increasing levels of greenhouse gases in the atmosphere."

Burning fossil fuels (oil, coal, natural gas) to run our power plants, vehicles and factories produces carbon dioxide, the most predominant greenhouse gas. The Earth's atmosphere acts like a pane of glass in a greenhouse, trapping the sun's heat in the lower atmosphere and causing the Earth's surface to warm.

Minnesota Experts and Economists Raise Flags

While total costs of some climate change impacts, such as heat-related illnesses and water quality issues, are still unknown, two costs are hitting people's pocketbooks now.

Already Paying the Price for Climate Change

The cost associated with climate change is real—not just a projection for the future. We are already paying the price.

Climate change makes weather events like severe drought more likely and is causing sea levels to rise.

As the frequency and intensity of extreme weather increases, so do our home insurance rates, the number heat-related health emergencies, and disturbances to our crops and other industries.

Disaster Costs

We also pay the costs of responding to climate-related emergency situations and rebuilding afterwards.

Since 1997, 32 severe weather natural disasters cost Minnesota nearly $500 million. This is the price we pay for not adapting ourselves. And, we will continue to pay the price if we do not work together.

Billions in Damages from Electricity Generation

University of Minnesota economists estimate the total annual health and environmental damages from electricity generation in Minnesota are more than $2 billion.

That is $800 million in health costs—largely related to respiratory and cardiovascular health impacts from "criteria air pollutant" emissions (sulfur dioxide, nitrous oxides, particulates, ammonia and volatile organic compounds).

More than $1.2 billion is from damages related to global climate change.

Emissions from coal-fired electricity generation contribute to more than 90% of the total damages.

Further, the American Lung Association estimates particulate matter from coal-burning power plants cause 24,000 premature deaths, 550,000 asthma attacks and 38,000 heart attacks per year nationally.

Drought and Floods at Once?

New precipitation trends have the potential to cause both increased flooding and drought, based on the localized nature of storms and their intensity, leaving parts of the state drenched and others dry. In 2007, 24 Minnesota counties received drought designation, while seven counties were declared flood disasters. "At first, we thought that vast discrepancy was a singularity, a sample of one," Dr. Mark Seeley said. **"But in 2012, 55 Minnesota counties received federal drought designation at the same time 11 counties declared flood emergencies.** Two times in 10 years is no longer a singularity."

Flooding in 2012 in Northeast Minnesota damaged roads and bridges, water and sewer systems and other infrastructure, costing $108 million. More than 1,700 homes and 100 businesses were damaged or destroyed, costing more than $12 million.

About that Polar Vortex — Earth Still Logged Its Fourth-Warmest January

Despite bone-chilling cold in Minnesota, the 2014 Polar Vortex was an icy blip in a hotter global story.

Meteorologist Paul Douglas explains: "We are all hard-wired to react to weather, not the longer, slower (global) climate trends that have so many scientists concerned. You'd never know it staring at the thermometer in your backyard, but the planet continues to run a low-grade fever." Here's a clip from Climate Central: "[January 2014] was the fourth-warmest January since recordkeeping began in 1880. It was also the 347th consecutive month with above-average temperatures compared to the 20th century average, which has been fueled in large part by climate change."

MINNESOTA'S ENERGY

An Aerial View

Reducing emissions that are causing climate change begins with understanding how we're using energy, where our energy comes from, and how energy choices are made. In Minnesota, we use most of our energy (80%) to earn a living and commute to and from work or transport products. The remainder is for keeping our homes comfortable, bright and connected.

Energy Sources

For at least a century, Minnesota's electricity system has been largely reliant on fossil fuels, 100% of which are imported from other states and countries. Today, Minnesota receives more than 55% of its electricity from U.S. coal-fired power plants, the biggest emitter of greenhouse gases in our state. However, in less than one decade, the state's use of coal has dropped by 33%.

Coal
Minnesota has historically relied heavily on coal to meet electricity needs. Our use of coal has declined in part due to environmental and health policies. It also has been heavily influenced by market forces—from increases in energy efficiency to decreases in the price of natural gas and renewable energy.

Nuclear
In the 2030s, Minnesota's nuclear power plants will reach the end of their current licenses. Important decisions need to be made about their future. As opposed to coal and natural gas, nuclear power omits no carbon. For that reason, pressure to reduce carbon may influence future discussions on nuclear.

Natural gas
Natural gas is a fossil fuel that Minnesota imports. Prices have fallen dramatically and U.S. supply has increased with the development of hydraulic fracturing. Even as this technology is widely deployed, the debate continues over environmental impacts and necessary environmental regulations.

Gasoline
Minnesota imports all of its gasoline, primarily from other countries. In 2012, the United States imported about 10.6 million barrels of petroleum per day from about 80 countries. Our imports decrease with increased domestic production, more efficient vehicles and the use of biofuels.

Clean Energy
Minnesota's energy portfolio changed dramatically over the past decade. We used less coal and more wind and natural gas sources to generate electricity. Today, renewables account for almost 20% of Minnesota's electricity generation annually, up from nearly 6% in 2000. Minnesota is not alone in this shift. Demand for electricity generation from renewables is expected to increase by 49% from 2012 to 2018 globally, according to the International Energy Association. Additionally, Minnesota now meets 10% of its gasoline demand with ethanol made primarily from corn.

$$$$$$
$$$$$$
$$$$$$

$13 BILLION

Minnesota annually imports $13 billion worth of energy, including fossil fuels such as coal, oil and natural gas, from other states and countries because we don't have them here.

Shaping Our Energy Portfolio

Many situations and considerations face policymakers as they adjust our energy portfolio to meet Minnesotans' needs, reduce emissions, strive for energy independence and economic growth, and ensure our health in the decades to come.

State Renewable Energy Standard Is Driving Change

Minnesota's 2007 Next Generation Energy Act is a law that requires utilities to generate at least 25% of their electricity from wind, solar and biomass by 2025 (30% by 2020 for Xcel Energy). Likewise, our state solar energy standard requires investor-owned utilities to meet 1.5% of their electricity needs from solar generation by 2020.

GREENHOUSE GAS EMISSIONS 23% LOWER

Due in large part to these laws, Minnesota's investor-owned utilities are on track to meet our state renewable energy goals. And, the Minnesota Pollution Control Agency estimates that annual greenhouse gas emissions in 2010 from the electric power sector were 23% lower than they would have been without the laws.

1 MILLION

Using wind to generate electricity in Minnesota reduces carbon dioxide emissions by more than 5.4 million metric tons each year, the equivalent of taking about one million cars off the road.

Energy Demand Is Growing

The energy we use for residential and commercial buildings, transportation, industry (including agriculture), and electricity production has increased over the past three decades.

Our growing population—partly responsible for growing energy demands—is projected to increase 13% by 2040 and up to 33% in some counties, placing increased pressure on transportation and building services.

Our Energy Future Is Our Choice

Minnesota is successfully cutting emissions by increasing energy efficiency, increasing the use of renewable energy, and switching from coal to natural gas at power plants. As we look to the future, we have critical decisions to make about our coal-fired and nuclear power plants, as well as how we integrate increasing amounts of renewable energy into our system. These choices offer opportunities to improve our air and water quality, protecting the health of our communities and ecosystems. Additionally, these choices challenge entrepreneurs and scientists to develop new businesses and to be innovative—and our communities to redefine "business as usual."

More than 2,600 solar panels sit atop the Minneapolis Convention Center and help directly power the facility. (Photo Credit: Minneapolis Convention Center)

MINNESOTA'S ENERGY

Our Clean Energy Economy

With an abundance of wind, solar and bioenergy—Minnesota is poised to grow our own clean energy economy, fulfill our own energy needs, and reduce our emissions. In fact, we already are well on our way. Minnesota is the fourth best state for favorable policies and the ninth best state in clean technology leadership, based on a review of technologies, state policies and access to capital. Four clean energy industries in Minnesota already have a strong base from which to grow local businesses. Representing huge potential earnings for clean energy workers, these industries are expected to add more jobs in Minnesota in the coming decades.

WIND

Minnesota generated nearly 16% of its electrical power from wind in 2013, ranking fifth nationwide. And, in 2013, landowners received more than $10 million in annual land-lease payments.

In 2011, large-scale wind power from the upper Midwest was available for just over 3 cents per kWh ($30/MWh), compared to new natural gas plants at 6-8 cents per kWh ($61–87/MWh).

SOLAR

Minnesota has as much sun to power solar panels—for seven hours a day—as Houston, Texas. This abundance—along with increasing demand for solar, decreasing solar prices and the state's aggressive renewable energy policies—could mean a boon for Minnesota companies in the solar market. Solar demand in the United States increased more than 33% in 2013, and solar energy consumption is projected to increase by roughly 19% in 2014. Driving demand for solar in Minnesota is the state's solar energy standard, which requires investor-owned utilities to meet 1.5% of their electricity needs from solar by 2020.

Solar module prices plummeted 40% from 2008 to 2012.

BIOENERGY & BIOCHEMICALS

We can replace petroleum with fuels and chemicals derived from plants. For more than a century, Minnesota has used its rich endowment of timber and farmland to become a pioneer in bioenergy. Today, the Department of Natural Resources and the Statewide Wood Energy Team are accelerating the substitution of high-cost fossil fuels, such as propane and fuel oil, with sustainably managed wood from Minnesota's forests.

The Minnesota Department of Natural Resources estimates that we could offset about 3% of our fossil needs with woody biomass.

ENERGY EFFICIENCY

The cheapest, cleanest energy is energy we don't have to produce, making energy efficiency an energy resource, just like wind or solar. Minnesota's Conservation Improvement Program requires an annual energy savings goal of 1.5% of retail sales for electric and natural gas utilities. The policy has saved electricity and gas customers millions of dollars over the last few decades and created thousands of stable jobs that cannot be outsourced, such as weatherizing (insulating) homes, installing new windows, and upgrading heating, venting and air conditioning systems and lighting. Today, Minnesota's energy efficiency firms employ about 9,000 people.

EFFICIENCY IS CHEAP

The cost to SAVE a kilowatt-hour of electricity is about 1.5 CENTS

The cost to BUY a kilowatt-hour of electricity is about 8 CENTS

DID YOU KNOW?

Renewables account for almost 20% of Minnesota's electricity generation annually, and our residential electricity rates are still consistently below the national average.

By the Numbers

CLEAN ENERGY JOBS

15,300+ *Minnesotans Work in Clean Energy*

More than 15,300 Minnesotans work in clean energy. In 2013, these workers added more than $1 billion in direct wages to the Minnesota economy.

75%+ *Growth in Clean Energy Jobs*

Minnesota's clean energy jobs grew more than 75% between 2000 and 2014. By comparison, the total Minnesota economy grew 11% during the same period.

BIOFUELS EXPORTS

79% *of Ethanol Is Exported*

Minnesota is such a large ethanol producer that we export 79% of what we make.

Success Stories

WIND

Xcel Energy has said that wind is now less expensive than a 20-year natural gas contract. The company is the nation's number one purchaser of wind power and operates two wind farms in Minnesota. The American Wind Energy Association named Xcel Energy its "2013 Energy Utility of the Year" for its commitment to wind power.

In 2012 alone, wind energy provided up to 2,000 direct and indirect jobs in Minnesota.

SOLAR

St. Paul-based **SimpleRay** predicts that by the end of the decade Minnesota's solar requirement could boost in-state solar panel sales by a factor of 40. Increasing solar demand, lower prices and aggressive renewable energy policies are driving market growth in Minnesota.

Minnesota solar businesses plan to hire 250 more workers through 2015.

EFFICIENCY

Minneapolis-based startup **SmartThings** developed a cloud-based infrastructure that allows users to control thermostats, lights and other household electronics from their smartphones. The company received $12.5 million in venture capital investment in 2013.

SmartThings technology makes it easy for consumers to save money and energy.

Downed trees and waste wood were taken from Frontenac State Park to generate energy.

BIOENERGY & BIOCHEMICALS

Climate adaptation, mitigation and economic opportunities can be linked to each other. In 2013, overgrown trees and invasive buckthorn were removed from Frontenac State Park to support landscape biodiversity. The waste wood was then brought to **District Energy in Downtown St. Paul** and directly used to generate enough energy to heat 90 homes for one year, displacing fossil fuel sources.

Segetis, a biochemical company in Golden Valley, uses plant-based chemicals to displace petroleum products that would otherwise be used in household products. The company's solvents can be found in Method laundry detergent and Seventh Generation cleaning products.

DID YOU KNOW?

From 2004 to 2013, Minnesota clean energy firms received **$422 million in venture funding**—more than Wisconsin, Iowa and North Dakota combined. Minnesota solar, wind and bioenergy firms also received **$10.87 billion in energy project financing**.

There is no magic bullet to stop climate change. To prepare for it, we can work together to implement thoughtful strategies that build Minnesota's resiliency, reduce future risks, and provide benefits for our economy, health and natural resources.

Shifting to cleaner, low-carbon energy sources is one part of the equation. Tracking our greenhouse gas emissions and identifying strategies to significantly decrease (or mitigate) them is another. Weaving in efforts that address how our health and natural resources are being harmed by climate change—and implementing ways to adapt—is also critical.

Some Progress, with More Work to Be Done
On the emissions front, between 2005 and 2010, Minnesota experienced modest reductions of 3%. Minnesota will miss its first greenhouse gas emissions reduction target of 15% by 2015.

However, due in large part to Minnesota's Renewable Energy Standard and energy efficiency efforts, **our electric utility sector is on track to reduce greenhouse gas emissions in 2025 by 33% below what levels would be without these programs**, demonstrating that Minnesota's aggressive energy laws and programs are working.

The Minnesota Environmental Quality Board coordinates interagency work and efforts across local, state and federal government to create long-range plans and review proposed projects that would significantly influence Minnesota's environment. The Board is leading efforts to address climate change in Minnesota and to ensure that all our communities are resilient to future risks and changes associated with our evolving environment.

The following pages showcase what Minnesota has been doing to address climate change, what's happening next, and how you can help.

WHAT IS MITIGATION + ADAPTATION?

MITIGATION
Reduce emissions to lessen future climate change impacts.

EXAMPLE ACTIONS

- Conserve energy
- Use renewable energy (wind, solar, biofuels)
- Drive energy-efficient vehicles
- Bike, walk and take public transit

ADAPTATION
Prepare for climate change impacts happening now.

EXAMPLE ACTIONS

- Plan for storms and heat waves
- Build resilient roads and bridges
- Improve stormwater management systems
- Protect waterways from erosion

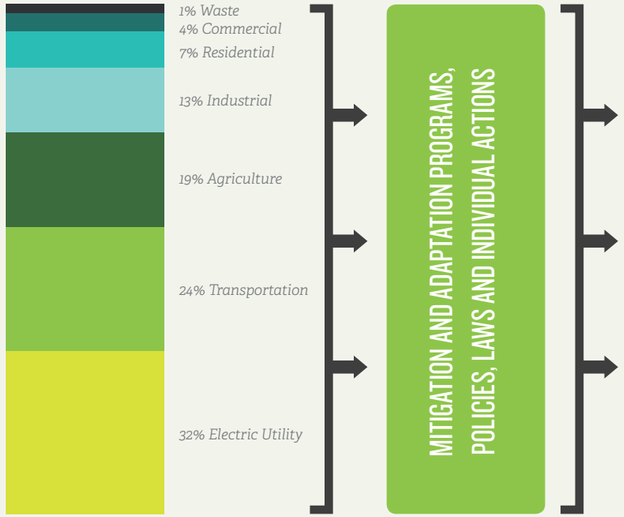
BOTH
Mitigation and adaptation often work together.

EXAMPLE ACTIONS

- Use water wisely
- Install "green infrastructure"
- Plant urban trees
- Use sustainable building practices

WHERE ARE WE TODAY?

Minnesota's Greenhouse Gas Emissions Sources



Our Actions

Core Metrics

3% ↓
Reduction in greenhouse gas emissions between 2005-2010. Minnesota will miss its goal of a 15% reduction by 2015.

NEARLY 20% ↑
The amount of renewables used for electricity generation annually is almost 20%, up from just 5.8% in 2000.

NEARLY 15% ↑
Clean energy employment grew 14.5 percent from 2012 to 2014, far faster than the 5.3 percent growth of the Minnesota economy overall.

Sector Highlights

ENERGY EFFICIENCY AND BUILDINGS
10
The number of medium-sized power plants that Xcel Energy has not needed to build thanks to efficiency programs in place since 1992.

HEALTH
1,255 ER Visits
The number of heat-related emergency room visits in 2011 statewide.

TRANSPORTATION
Driving Less
After decades of near constant growth, vehicle miles traveled stopped increasing in 2004 and leveled, despite population growth.

NATURAL RESOURCES
5.8 Billion Metric Tons of Carbon Dioxide
Minnesota's forests store the equivalent of about 5.8 billion metric tons of carbon dioxide.

WASTE
$8.5 Billion in Economic Activity
Minnesota's value-added recycling manufacturers generated approximately $8.5 billion in total economic activity, including sales, compensation and tax revenue, and supported nearly 37,000 jobs in 2011.

AGRICULTURE
10%
The amount of gasoline used by Minnesotans that's now displaced by corn-based ethanol.

ENERGY EFFICIENCY AND BUILDINGS

Minnesota is succeeding in reducing emissions in our electric utility sector—the engine fueling our buildings and industry. Shifting to cleaner energy is a big part of our progress, but energy efficiency is just as powerful. Minnesota's energy efficiency incentives and programs, which have been implemented by utilities, have changed how we use electricity in our homes, construct our buildings and operate our businesses. We're cutting wasted energy and putting money back into our economy with energy savings—proving that with energy efficiency, we can do more with less.

By the Numbers

10 *Power Plants*

The number of medium-sized power plants that Xcel Energy has not needed to build in its territory thanks to efficiency programs.

Nearly 2 Million *Tons of CO_2 Saved*

The number of tons of carbon dioxide that were saved through energy efficiency efforts in Minnesota between 2010 and 2011. This is the equivalent of removing about 400,000 cars from the road each year.

8.5 to 1.5 *Return on Investment*

In Minnesota, utility conservation programs returned an average of 8.5 cents per kWh for every 1.5 cents spent for measures implemented in 2010 and 2011.

WHAT'S HAPPENING?

One Energy Savings Goal, Endless Opportunities

Energy efficiency efforts in Minnesota have been in place since the early 1980s through the state's **Conservation Improvement Program**. In 2007, Minnesota took another big step forward. We added one of the strongest energy efficiency standards nationwide, requiring electric and natural gas utilities to achieve an annual energy savings goal of 1.5% of their retail energy sales.

Today, Minnesotans are incentivized with a variety of tools to save energy and money as a means to a critical end: greater emissions reductions. With utility energy efficiency and rebate programs and a host of state and federal grants and loans, Minnesotans should consider their buildings and industries powerful partners in mitigating the effects of climate change.

HOMES

We use energy to heat and cool our homes, cook our meals, take hot showers, and power our electronic devices and appliances. Extreme temperatures demand greater energy use, causing Minnesotans' energy bills to change from year to year. In 2012, according to the U.S. Energy Information Administration, the average Minnesota household spent $1,875 on utility costs each year. Minnesotans are lowering their energy bills and emissions by participating in their utilities' energy efficiency programs, retrofitting existing homes and constructing new homes to high energy standards.

Energy Savings Tools

Building Energy Codes—Minnesota uses the most efficient codes in the nation so that new homes avoid air leaks, inefficient lighting, heating and cooling equipment, and more.

Home Energy Reports—Some Minnesota utilities provide reports that show how much energy we use compared to our neighbors. In just two years, the reports helped Minnesotans save $6 million in utility bills.

Energy Efficiency Home Improvement Loan Program—Homeowners can access unsecured, low-interest loans for energy efficiency upgrades to their homes through the Minnesota Housing Finance Agency.

Paying Off

The first Twin Cities Habitat for Humanity Net Zero home in north Minneapolis is built to the highest levels of energy efficiency, insulated at least three times as much as a regular house and sealed extremely well to keep drafts out.

The first LEED Gold-certified, multi-family residential project created in Minneapolis was completed in 2013. The design of 7west, a 213-unit apartment building, incorporates features that go beyond typical sustainable construction and energy conservation techniques.

BUSINESSES

In any business, it takes energy to keep the lights on, keep spaces comfortable for workers and customers, and run equipment and appliances. In 2012, according to the U.S. Energy Information Administration, Minnesota's commercial sector spent about $2.8 million on energy. Experiencing energy inefficiencies in any business is like watching hard-earned money blow out of a drafty doorway. Minnesota businesses and commercial buildings are seizing opportunities to save energy and grow their bottom lines.

Energy Savings Tools

U.S. Department of Energy State Energy Program (SEP)—We receive federal funds for state energy efficiency and renewable energy programs that help reduce U.S. emissions. Every $1 of the federal-state SEP partnership yields $7.23 in energy cost savings.

Trillion BTU—A business loan program developed by the St. Paul Port Authority and Xcel Energy has funded $25.5 million in project costs, financed 53 projects, and saved or created 890 jobs.

PACE (Property Assessed Clean Energy)—This financing tool helps businesses make energy efficiency retrofits on their properties and pay them back through their mortgages.

Paying Off

St. John's Hospital, Maplewood, received $875,000 from Trillion BTU and other sources to help finance a $1 million building automation and efficiency project for its air, heating and cooling systems. $200,000 per year in energy savings are projected.

Iron Range Resources & Rehabilitation Board

The Iron Range Resources and Rehabilitation Board has a project to assist Hibbing businesses with energy efficiency decisions and financing for energy retrofits. Energy savings from 13 projects are expected to save more than $70,000 a year. Projects employed 18 local contractors and 13 local vendors, yielding 4,900 hours of work.

PUBLIC BUILDINGS

Energy cost savings in public buildings free up taxpayer money for other priorities. In Minnesota, energy efficiency efforts help achieve a state goal to reduce total energy consumption by 20% throughout all state agencies by 2020. If achieved, Minnesota will reap an estimated $5.3 million in energy savings.

Energy Savings Tools

Guaranteed Energy Savings Program—Energy-savings contractors pay the upfront cost of retrofits in our school districts, local governments and state agencies, and higher learning institutions. Costs are paid back through energy savings from the installations.

GreenStep Cities/GreenCorps—Minnesota's GreenStep Cities is a voluntary program to help communities achieve their sustainability and quality-of-life goals. GreenCorps professionals work with communities, nonprofits and educational institutions on energy conservation efforts.

SB2030 Standards—Construction and renovation of large public buildings in Minnesota must meet a mandatory set of design standards that reduce energy use and carbon intensity.

Paying Off

Energy consumption in the Capitol Complex was reduced more than 20% from 2008 to 2013, saving an estimated $2 million in utility costs.

The Minnesota History Center has reduced energy consumption 53%, carbon emissions 37% and energy costs 35% over the last seven years.

LOOKING AHEAD

Minnesota is investigating what it would mean to incorporate higher levels of renewable energy and energy efficiency into our electricity sector. The growing momentum of clean energy will require entrepreneurship, innovation and the public to get involved. Some technologies that might become more important are combined heat and power, solar hot water heaters, energy storage, anaerobic digestion and net-zero energy building techniques.

DO YOUR PART

Understand your electricity and gas use.
The Environmental Protection Agency's free Home Energy Yardstick software program assesses a home's energy use. Enter information from your utility bill to get started.

Participate in your utility's energy efficiency rebates and programs to save money and reduce emissions.

Buy energy efficient appliances and equipment.

HEALTH

With more powerful and intense weather events upon us today, human health is now a leading climate change issue. Extreme weather increases flooding, overwhelming storm water systems and potentially contaminating recreational and drinking water, which may be in short supply due to drought. Heat illness, respiratory problems, food security and property loss add to the list of concerns among public health officials. Minnesotans can learn about climate-induced health risks, and towns and cities statewide can make changes that build their resilience and improve their communities.

By the Numbers

Estimated damages from air pollutants emitted by electricity generation each year. These pollutants cause most harm to humans near the source who suffer from asthma and cardiovascular disease.

Estimated damages to property in Minnesota due to extreme weather between 2000 and 2012.

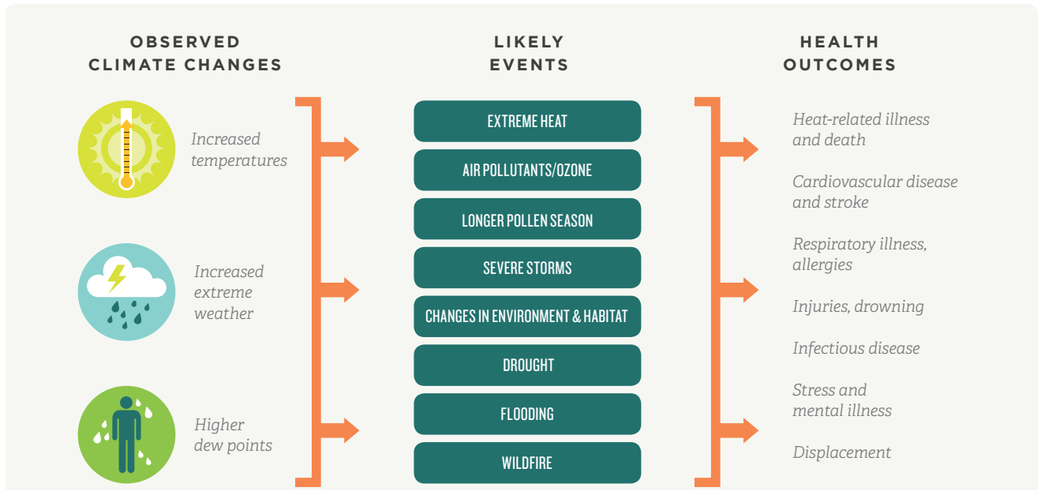
The number of heat-related emergency room visits in 2011 statewide, 168 more than the previous decade's high of 1,087 visits (2001).

WHAT'S HAPPENING?

Climate Cause and Effect: When Health Professionals Get Involved

How people's health is affected by climate change can be as complex as it is overwhelming. Obvious problems are heat stroke and exhaustion; injuries sustained from extreme weather; or asthma aggravated by poor air quality. But what about food safety or an influx of heat-loving, disease-carrying ticks and mosquitoes?

Climate change impacts human health in many ways, including extreme heat, water and air quality, agriculture and food security, and mental health. Some populations are more vulnerable than others, including children, the elderly, and people living in poverty. They are particularly susceptible or lack resources to respond to bad air days, heat waves or storms.

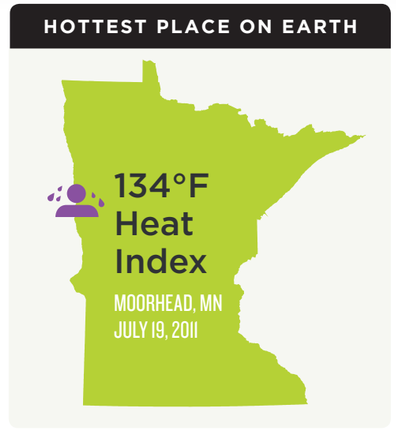


LOOKING AHEAD

With powerful storms forecasted for years to come, towns are investing in safety and taking steps to reduce future damages. The Division of Homeland Security and Emergency Management (HSEM) helps towns envision their future, offering grants and planning resources for "mitigation measures" that reduce or eliminate the severity of future disasters. For example, when a 1,000-year flood hit Zumbro Falls in 2010—its fourth significant flood since 1970—community leaders had enough. The town of 200 secured $1.9 million in city, state and federal funds to buy out 14 homeowners and one business on "Water Street," preventing future damage and protecting residents. The green space now provides an area for community festivals and cultural events, showing that good can come from painful changes. Also with HSEM's help, Wadena-Deer Creek added a tornado-safe room to its school. And, Moorhead secured a new water pumping system so water is safe to drink during the Red River Valley's flood season.

Keeping Our Cool When Heat Hits

When Moorhead was the hottest place on Earth with a heat index of 134°F on July 19, 2011, only two Minnesota public health departments had a heat-response plan. That summer, five heat episodes resulted in heat advisories or warnings, and the number of emergency department visits statewide alarmed state health officials. To help prepare communities, the Minnesota Department of Health developed the **Minnesota Extreme Heat Toolkit**, offered online and through trainings. The agency also helps communities map populations that are vulnerable to heat-related illness against other risk factors, such as lack of resources. For example, the Minneapolis Health Department and the Minnesota Department of Health used Geographic Information System (GIS) maps to pinpoint where Minneapolis residents could access a public building with air conditioning during a heat wave.



Improving Our Air Quality

A 2001 state law allowing Minnesota utilities to recover the costs of moving to cleaner technology with a modest cost to customers improved metro-area air quality. Xcel Energy's Metropolitan Emissions Reduction Project added state-of-the art emissions controls to its Oak Park Heights plant and converted coal-fired plants in northeast Minneapolis and near downtown St. Paul to natural gas. **As a result of Xcel Energy's overall project efforts, emissions that can cause respiratory diseases dropped by more than 90% and carbon emissions fell 21%. Customers paid less than expected, and the plants' total production increased.**

Converted for natural gas production, the Xcel Energy High Bridge Generating System in Saint Paul came on line in May 2008.

Create your extreme weather emergency plan.

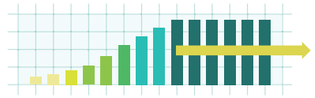
Heed heat advisory, storm and air-quality warnings.

Drive less and walk more to boost your health and cut your use of gasoline.

TRANSPORTATION

Over the last decade, Minnesota has seen transportation-related emissions decline with a combination of people driving less and using more fuel-efficient vehicles and lower-carbon fuels. Reductions are expected to continue if we do more of the same. However, opportunities for greater reductions are linked to questions of how to meet growing demand for cleaner, more efficient transportation and update Minnesota's aging transportation infrastructure. Extreme weather adds to the challenge. Harsh winters cause outbreaks of potholes that strain city, county and state budgets. And, flooding events can severely damage roadways, debilitating communities and costing millions.

By the Numbers

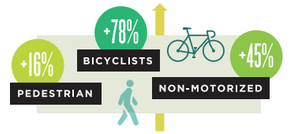


Driving Less

After decades of near constant growth, vehicle miles traveled stopped increasing in 2004 and leveled, despite population growth.

Using Less Fuel

Since 2007, annual transportation fuel usage dropped by more than 10% due to more fuel-efficient vehicles and decreases in driving and other factors.



More Transit Use, Biking and Walking

Transit ridership hit 105 million in 2011, an overall increase since 2003. Biking and walking in Minneapolis and Saint Paul has increased markedly from 2007–2013.

WHAT'S HAPPENING?

From Point A to Point B with Less Impact

Congestion and idling consumes more fuel and adds emissions. These traffic management practices from the Minnesota Department of Transportation (MnDOT) keep us moving.

Roundabouts eliminate idling at signals, reducing vehicle emissions and fuel consumption by 30% or more.

300 miles of bus-only shoulders in the metro have for decades allowed buses to bypass congestion, increasing ridership.

MnPASS lanes provide an alternative to heavy traffic. Solo drivers pay; buses, carpools and motorcyclists do not.

Transitioning from Gasoline to Renewable Fuel Sources

By 2015, Minnesota aims to displace 14% of petroleum with biofuels, such as ethanol and biodiesel. Biofuels can reduce vehicle emissions and decrease our reliance on imported oil. Through a public-private partnership, the **Drive Electric Program** is expanding charging stations for electric vehicles, which reduce emissions by about 40% compared to gas-powered vehicles. Public stations are installed at 150-plus sites, including the Minneapolis-St. Paul Airport, the Depot in Duluth, downtown Rochester, and metro ramps and parking lots. Down the road, wind- or solar-generated electricity may power stations, reducing emissions even more.

30% *Minnesota's goal is to transition 30% of our gasoline to biofuels by 2025.*

Metro Transit reduced CO_2 exhaust emissions and saved more than $300,000 over a five-month period in 2013 by using B-10 and B-20 fuel blends in its buses.

St. Cloud is the nation's first city to have a public bus powered by recycled vegetable oil.

LOOKING AHEAD

The Metropolitan Council predicts the seven-county metro region will add 800,000-plus people by 2040. While not all cities in the state will continue to grow, jobs and services are consolidating in small urban areas and regional centers. As the population distribution changes, we may need to expand our public transit and design more bike-friendly and walkable communities.

Paving the Way for Low-Emission Travel

Choosing to walk or bike instead of driving for trips less than one mile can significantly decrease carbon emissions. You can lower your emissions further with longer trips. Minneapolis is consistently recognized as one of the most bike-friendly communities in the United States, reducing tens of thousands of tons of carbon per year.

Reconstructed Highway 68 in Marshall

MnDOT's Complete Streets policy ensures roads in any size community work for everyone. Walkers, bicyclists and transit users can safely travel to their destinations. Reconstructed Highway 68 through Marshall features bike lanes, sidewalks, curb bump-outs, and better lighting.

*Climate-friendly land-use and development planning helps reduce miles traveled. "Region 5"—Cass, Crow Wing, Morrison, Todd and Wadena counties—uses **Resilient Region** planning strategies and tools to incorporate long-range transportation plans for Safe Routes to School and bike and walking paths.*

Building Roads to Withstand Extreme Weather

In recent years, intense rains and floods have cost Minnesota communities hundreds of millions in damage to roads and bridges. **Minnesota is starting to dedicate resources to fortify key roads, including $50 million for the Statewide Flood Mitigation Program.** By 2016, approximately 30 projects in towns across the state, from Ada to Ortonville and Chanhassen to Breckenridge, will be completed.

Economic Win-Win: Connecting People to Jobs

Mass transit—including light-rail and bus rapid transit—reduces emissions by taking drivers off the road. It also connects thousands of Minnesotans to jobs. In a two-year period after light-rail service began, the number of low-wage jobs reachable within 30 minutes of transit travel jumped by 14,000 in light-rail station areas and 4,000 in areas with direct rail-bus connections. As light-rail extends into suburban locations, it will link to some of the region's largest employers. Along the proposed Green Line Extension, for example, UnitedHealth Group is building a 70-acre campus for 6,700 employees in Eden Prairie near a planned light-rail station.

DO YOUR PART

Drive smart—go easy on the brakes and idle less.

Take the bus, bike or walk when you can.

Choose the cleanest, most fuel-efficient vehicle you can.

For more tips, visit the Environmental Protection Agency's Transportation and Climate webpage.

DID YOU KNOW?

Ongoing and projected vehicle fuel economy improvements, in part driven by federal fuel efficiency standards, will reduce emissions that are equivalent to taking millions of vehicles off of the road.

AGRICULTURE

Over time, longer growing seasons and more carbon dioxide in the atmosphere from climate change may boost crop yields, but extreme weather swings and invasive species may increase the risk of crop failure. If Minnesota agriculture were disrupted, it would impact our economy and affect the global food supply. On the flip side, agriculture plays a role in climate change, releasing emissions through fertilizer application and certain field practices. Farmers face critical decisions about how to meet a growing population's needs, while protecting the environment—the foundation of their livelihood and everyone's quality of life. There are no easy answers, but state leaders, farmers and agricultural businesses will need to work together to address this challenge.

By the Numbers

ECONOMIC IMPACT

$75 billion *per year*

In Minnesota, agriculture and related businesses generate approximately $75 billion per year for our economy and employ nearly 350,000 people.

BIOFUELS

12,600 jobs *and $5 billion*

Total jobs and economic output, respectively, from Minnesota's ethanol industry in 2011.

10%

The amount of corn-based ethanol Minnesotans use instead of gasoline. In 2011, Minnesota exported 880 million gallons, or 79%, of the ethanol it produced.

WHAT'S HAPPENING?

Displacing Fossil Fuels with Energy from Plants

The agriculture industry is producing homegrown energy in a number of ways, keeping energy dollars in Minnesota and reducing the state's fossil fuel consumption. "Bioenergy"—energy from organic matter, such as plants, wood or residues from agriculture or forestry—can provide biofuels for transportation and biomass for electricity and heat.

Biofuels

Biofuels displace the amount of fossil fuels that we use. In Minnesota, corn-based ethanol and soybean-based biodiesel have reduced our fossil fuel usage and grown our rural economy by billions of dollars.

188,000

Minnesota's current biofuels mandates for ethanol and biodiesel, including the increased biodiesel mandate effective July 1, 2014, are projected to reduce CO_2 emissions by nearly 874,000 metric tons, the equivalent of taking 188,000 cars off the road each year.

By 2015, Minnesota aims to transition 14% of our gasoline to biofuels. (By 2025, we are striving for 30% in biofuels.) Minnesota was the first state to mandate the use of ethanol in its fuel supply. In doing so, the state moved from substandard air quality to achievement of the Clean Air Act standard by the mid-90s.

Advanced Biofuels

In a retrofitted ethanol plant in Luverne, GEVO, a renewable chemicals and advanced biofuels company, produces isobutanol. With 30% more energy content than conventional biofuels, isobutanol already is used as jet fuel in army helicopters and as a replacement for fossil-fuel-based chemicals for making plastics, rubber, textiles, paint solvents and more.

Biomass

Biomass from agricultural and forestry byproducts can be used to produce heat and electricity.

Koda Energy

A combined-heat-and-power plant in Shakopee, Koda Energy is a joint venture with Rahr Malting Company and the Shakopee Mdewakanton Sioux Community. Koda Energy burns agricultural and plant seed byproducts to create steam to generate energy in the form of electricity and heat. Rahr Malting uses residual heat from electricity generation in its malting process, replacing natural gas usage. The community is exploring burning native prairie plants in Koda Energy's facility, which could drive conversion of less-productive cropland to grassland cover and energy crop production; reduce agricultural runoff; and create wildlife habitat.

General Mills provides Koda Energy about 160–200 tons of oat hulls from the processing of its cereals each day.

LOOKING AHEAD

Questions about rising on-farm emissions and protecting water quality are pressing, particularly when crop prices are fluctuating and land prices are high. Between 2007 and 2012, higher crop prices, increased land values and fewer federal conservation incentives encouraged conversion of about one million acres of Minnesota conservation and pasture land to row crops, lowering carbon sequestration. On the horizon, cutting-edge projects offer potential new opportunities to reduce emissions. For example, the University of Minnesota's West Central Research and Outreach Center in Morris has launched a process that takes energy from wind, converts it to hydrogen, and then to ammonia that can be used as fertilizer on surrounding farmlands. Fertilizer accounts for a significant portion of corn production's carbon footprint. Producing fertilizer in a renewable way could significantly reduce its impact.

Protecting Our Waters

When it rains or when snow melts, water runs off of farm fields, carrying sediment, fertilizers and pesticides to ponds, lakes and streams. The **Minnesota Agricultural Water Quality Certification Program** helps farmers adopt on-farm conservation practices that protect nearby waters from agricultural runoff—a critical step in preserving our water quality as we adapt to climate change.

Grassed waterways in the Root River watershed in southeastern Minnesota prevent soil erosion while draining runoff water from adjacent cropland.

Farmers receive technical assistance and a combination of federal and Minnesota Clean Water Legacy funds for a variety of activities, such as removing excess pollutants by filtering water through grasses and other vegetation; adopting tilling methods to minimize erosion; and drainage methods that reduce water runoff into waterways. Upon certification, a farmer will obtain regulatory certainty for a period of 10 years. The program—piloted in four watersheds touching Olmsted, Wabasha, Winona, Stearns, Jackson, Martin, Faribault, Wilkin and Otter Tail counties—could become a model for other parts of the country.

Reducing Emissions by Changing the Way Business Is Done

Minnesota farmers are improving their bottom lines—and reducing their carbon footprints—by changing the way they work. For example, with new technology and seed quality, tractor trips across fields are reduced, lessening emissions. Fertilizing crops with a precise amount at the right time, with the right techniques, keeps nutrients in the soil and lowers nitrous oxide emissions.

Using renewable energy sources on the farm, cover crops and livestock grazing are other strategies. For example, cover crops can be planted when the soil would otherwise be bare before a crop emerges in spring or after fall harvest. These grasses, legumes or other plants improve soil fertility, hold nutrients for the next crop, help sustain ecosystems for wildlife, and improve the land's ability to absorb carbon.

Cover Crops

Grasses, legumes and other plants keep soil covered and sequester carbon.

Ian Cunningham, a fourth-generation farmer in Pipestone, plants cover crops and tills his land less to increase his soil's health and the likelihood cash crops will be more profitable. A mix of annual grasses, broadleaves and winter cereals, grown between corn and soybean crop seasons, also reduces stormwater runoff and helps the soil retain moisture, especially during dry periods. After harvest, Cunningham's cattle graze cover crops and crop residue, such as cornstalks, reducing feed costs and naturally fertilizing the soil.

Renewable Energy

Solar power can help reduce on-farm energy use and emissions, and save money.

Years of heavy rains and flash flooding near Featherstone Farms in Rushford caused owner Jack Hedin to consider the future of agriculture, climate change and how he could reduce his 250-acre farm's energy use and increase its efficiency. With financial assistance from the Minnesota Department of Agriculture, customers and friends, Hedin installed a 38-kilowatt photovoltaic array on a shed roof, which powers about half of his farm's operations.

DO YOUR PART

Learn about how your food is grown. Start by visiting the Minnesota Grown website.

Purchase food from local producers at your grocery store or farmers market.

Try renewable fuels.

NATURAL RESOURCES

Minnesota's lakes and rivers, towering pines, rolling prairies and wetlands are iconic. But these trees, waters and lands also are an important part of our economy, home to wildlife and where we go for outdoor recreation. They also contribute to the big climate picture: America's forests, grasslands and wetlands absorb about 40% of our greenhouse gases. How to sustain the diversity and health of Minnesota's natural resources so they mitigate climate change—and build resilience to it—are questions facing us now. Conservation is one answer.

By the Numbers

WATER USAGE ON THE RISE

1.4 Trillion *gallons of water per year*

Minnesotans' overall water use has risen from about 850 billion gallons per year in the mid-1980s to almost 1.4 trillion gallons per year in 2010.

CARBON REDUCTIONS, NATURALLY

15 Billion *metric tons of CO_2*

Minnesota's peatlands are estimated to store the equivalent of about 15 billion metric tons of carbon dioxide.

5.8 Billion *metric tons of CO_2*

Minnesota's forests store the equivalent of about 5.8 billion metric tons of carbon dioxide.

WHAT'S HAPPENING?

Water

Minnesota is known as the "Land of 10,000 Lakes," but our **surface water** resource actually includes 11,842 lakes greater than 10 acres and nearly 70,000 miles of rivers and streams. Our **groundwater** resource includes several aquifers that support about 400,000 drinking water wells. As the headwaters of the Mississippi, Great Lakes and Red River, virtually all of Minnesota's available water comes as rain and snow.

Climate change leads to problems with too much and too little water. Ensuring the water we have remains clean and abundant requires wise management and conservation.

Too Much Water

Intense storms cause flash and river flooding, putting the quality of our water at risk. When stormwater flows over land and pavement, it gathers trash, chemicals, animal waste and other contaminants that can pollute waterways and drinking water.

One inch of rain falling on a one-acre parking lot (about the size of a football field) generates enough stormwater runoff to fill three 9,000-gallon semi-tanker trucks.

Increased flows can overwhelm our water infrastructure, such as storm sewers. We can minimize the magnitude of stormwater runoff and flooding—while improving water quality—by restoring wetlands, which store and filter excess water. Innovative technology helps, too. For example, green infrastructure uses trees, shrubs and rain gardens to manage rainwater where it falls, before it flows to waterways. Its vegetation also beautifies landscapes and reduces emissions.

Maplewood Mall
55 rain gardens, 6,733 square feet of permeable pavers, 375 trees, and one decorative 5,700-gallon cistern built to catch stormwater greet visitors. Together, they help intercept 20 million gallons of runoff per year before it reaches nearby Kohlman Lake.

Too Little Water

Minnesotans use water for drinking, cooking and sanitation; growing crops and lawns; running businesses; and generating electricity. Water also supports natural habitats and contributes to our quality of life.

Our water supplies are at risk from drought and overuse. And, less predictable rainfall poses further challenges. When rain falls hard and fast, for example, it lowers the likelihood that water will saturate sub-soils and recharge or "refill" our aquifers, decreasing our water supply. Our growing population and development, which require more water, add to these challenges.

Efficient use and careful management are needed to sustain many water-dependent habitats and businesses.

Bob and Steve's Shell

Facing well levels nearly 12 feet below the 16-year average in Worthington in 2014, the gas station decided to stop selling its top two car washes to help conserve water. The move saved about 30% of the station's water usage, while only reducing revenue slightly.

LOOKING AHEAD

Ensuring sustainable use of our groundwater and protecting its quantity and quality are key concerns for our future. Studying our demand for groundwater and methods to protect this water source and ecosystems for future generations are underway. The Department of Natural Resources is piloting Groundwater Management Areas in three areas with stressed resources: the north and east metro, the Straight River area and Bonanza Valley. The projects will help state agencies, local communities and water users understand how to work together to address groundwater challenges.

Trees

Trees sequester, or absorb, carbon dioxide from the atmosphere. They convert the carbon dioxide into oxygen, which they release. They store the remaining carbon in their wood.

In one year, an acre of trees absorbs the same amount of carbon dioxide produced by driving a car 2,700 miles. The DNR manages more than 3.5 million acres of state forestland with sustainable management practices that improve carbon retention, soil quality and habitats.

Conserving Carbon Reducers

Minnesota Forests for the Future Program uses state, federal and private dollars to protect large blocks of private forestland that could instead be converted to other land uses. These easements protect our forests' carbon-storing capacity and conserve timber-related jobs; increase public access for recreation; and build our resiliency to climate change. Continuous forests speed recovery from wildfires, floods and droughts, and preserve animal and plant habitats.

The Upper Mississippi Forest Project protects more than 187,000 acres of northern forests; more than 60,000 acres of wetlands; and 280 miles of shoreline. A working forest, the property supplies 17 manufacturing facilities supporting more than 3,200 families. Combined with adjacent public forestlands, the project connects more than 4,000 square miles of uninterrupted habitat.

A New Way Of Planting

Community tree gravel beds—irrigated boxes filled with gravel—hold bare root trees for three to six months. The trees develop a dense network of roots, increasing chances they will survive once planted and thrive for generations. More than 25 Minnesota communities use gravel-bed systems, from Hendricks (pop. 700) to Rochester. Building on its own success, the Sherburne County Soil and Water Conservation District established a tree gravel bed for six communities in the county to share.

The Helping Tree

One large tree provides almost $4,000 in environmental and other benefits over its lifetime. Here are just a few:

Trees near buildings can reduce the demand for heating and air conditioning.

Tree-filled neighborhoods report lower levels of domestic violence, are safer and more sociable, and reduce stress.

Land

Sound land management prepares us for a changing climate and provides an opportunity to store and capture carbon. Preserving and restoring wetlands, prairies and grasslands, and buffer zones by lakes and streams, reduces the vulnerability of ecosystems, wildlife populations and critical carbon stocks.

With climate change, Prairie Pothole Region wetlands could shrink and shift optimal waterfowl breeding conditions from Canadian prairies and the Dakotas into western Minnesota. Without major restoration efforts to replace drained wetlands there, ideal habitat for ducks could gradually disappear.

Striving for Balance

Minnesotans made a significant commitment to conservation by passing the **2008 Clean Water, Land and Legacy Amendment**. Funded by the amendment, the Minnesota Prairie Plan balances the needs of prairie-wetland ecosystems with working farmland, including cropland and pastureland. Its goal is to protect remaining prairies and connect them with a corridor of high-quality habitat for wildlife such as ducks, meadowlarks and Monarch butterflies. The plan's goals have multiple co-benefits including protecting and increasing the carbon stored in grasslands and wetlands and enabling greater ecological resilience to climate change.

Plant trees and other native plants in your yard and community. Visit the Minnesota Shade Tree Council website to learn more.

Use water wisely. Get started on the Minnesota Pollution Control Agency's Conserving Water webpage.

Collect rainwater and use it to water your lawn.

WASTE

Managing our trash and wastewater—the water we use for washing, flushing and manufacturing—emitted nearly 2.3 million tons of greenhouse gases in 2010. While our waste-handling emissions have risen, towns and businesses are working to decrease pollution, turning waste into opportunity. Most waste-related emissions are from methane-producing landfills. Minnesotans can help by reducing their waste and reusing, recycling and composting more. Reducing electricity we use to manage our waste and wastewater is also critical.

By the Numbers

CAPTURING POLLUTION

2.1 Million Tons *GHGs Captured*

Over the last decade, Minnesota has steadily captured and controlled more methane emissions from solid-waste landfills. In 2011, about 2.1 million tons of greenhouse gas emissions were captured, a roughly 50% increase from 2000.

ECONOMIC IMPACT

46,000 *Full-Time Jobs*

More than 46,000 full-time workers are employed by Minnesota businesses that deal in rented, repaired or reused goods. The businesses generate $1 billion in wages and $4 billion in sales annually.

$8.5 Billion *in Economic Activity*

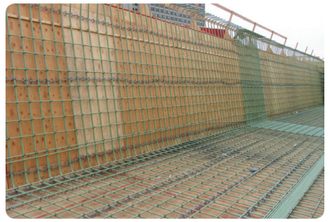
Minnesota's value-added recycling manufacturers generated approximately $8.5 billion in total economic activity, including sales, compensation and tax revenue, and supported nearly 37,000 jobs in 2011.

WHAT'S HAPPENING?

Reduce, Reuse, Recycle and Compost—And Boost Our Economy

An effective way to reduce greenhouse gases from landfills is to put less in them. Reducing what we consume; recycling and composting more of what we throw away; and reusing items or repairing and renting what we need (rather than buying new) can significantly reduce emissions. These practices also provide tens of thousands of jobs and billions of dollars in economic activity in Minnesota.

Recycle More, Add Jobs



*From 2004 to 2011, nearly 6,200 direct jobs were created by Minnesota recycling manufacturers—companies that make products from recycled materials and their suppliers. **Gerdau Ameristeel**, South St. Paul, is one of 200 Minnesota recycling manufacturers that prefer locally sourced recyclables for their products. The company uses steel cans from your curbside collection to make steel rebar, 7 million pounds of which was used to help rebuild the 35W bridge.*

Composting Together

***Full Circle Organics Recycling Cooperative and Dodge County** collect food waste from grocery stores and restaurants, combining it with yard waste to produce garden and landscape compost. In a two-year pilot, Erdmans County Market in Kasson diverted 56 tons of food trimmings and waste. That's 28 tons of rich soil for gardeners and landscapers.*

Rethinking Curbside Recycling

*Since switching to single-sort recycling in 2013, **Minneapolis** has experienced a 33% increase in the volume of recyclables collected in about one year. **Winona County** has added curbside collection countywide, both single-sort and expanded-plastic collection. Ninety-six percent of Winona County residents are participating in the new program. Cities and counties with single-sort recycling can maintain participation at these levels with continuous and regular education.*

Lost Opportunity

Minnesota recycling programs collected material worth almost $700 million in 2010, yet Minnesotans discarded 1 million tons of recyclables worth $210 million and spent $200 million to dispose of it.

More than 70% of landfill waste could be recycled or composted, conserving resources and preserving landfill capacity.

LOOKING AHEAD

"Doing more of everything"—from recycling to composting in any town, home or business—will greatly reduce our emissions from waste. By 2030, seven metro-area counties hope to achieve aggressive waste-related goals. To that end, they are now implementing a number of activities, such as assisting businesses in expanding what they reuse and recycle and offering fix-it clinics for anyone wanting to repair small appliances, electronics and more. At a state level, an adjustment to Minnesota's composting rules aims to increase opportunities for people to compost at home. Certain composting facilities will face fewer regulatory requirements when accepting organics, such as food and yard debris, separated from other waste.

Landfill Gas—Converting a Problem into Power

As landfill-waste decomposes, it produces methane, a greenhouse gas with global warming potential more than 20 times as potent as carbon dioxide. To tackle this problem, some Minnesota landfills capture and convert methane into electricity, heat or fuel for equipment. Besides decreasing methane gas in the atmosphere, the process produces renewable energy and avoids carbon emissions from fossil fuels.

The **Crow Wing County Landfill** in Brainerd collects its landfill gas and uses a portion of it to heat a maintenance building, replacing natural gas. The remaining landfill gas is flared, or destroyed.

Minnesota has 21 landfills in operation, nine of which employ gas collection and recovery systems. Statewide, 109 closed landfills (full and monitored for pollution) participate in the voluntary Closed Landfill Program. A number of these landfills captured and prevented a combined 28.4 million pounds of methane gas from entering the atmosphere in 2012.

Using Less Electricity at Wastewater Treatment Plants

Pumps, motors and other equipment that clean and recirculate water used in our homes and workplaces run around the clock. That's why water and wastewater facilities are among the largest users of a community's energy—and the largest contributors to its emissions. Electricity accounts for 25% to 40% of a wastewater utility's operating budget. Cities reduce their plants' energy use by conserving water, which lessens the amount of water that must be treated; investing in new, more efficient equipment; and switching to renewable energy.

Metropolitan Council Environmental Services saves $600,000 annually after switching Blue Lake, Minnesota's fourth-largest wastewater treatment plant, from natural gas to renewable "biogas" generated by anaerobic digesters. The Shakopee plant produces biogas equivalent to the natural gas usage of nearly 820 Minnesota homes. Additionally, 10% of Blue Lake's power will come from on-site solar panels in the near future.

The Blue Lake wastewater treatment plant treats an average of 29 million gallons of wastewater per day.

Think before you open your garbage can. Most materials can be recycled or composted instead.

Learn what you can recycle and compost in your county.

Start a backyard compost pile for food scraps, yard trimmings and other organic waste.

Buy used goods, not new, when possible.

DID YOU KNOW?

Habitat for Humanity ReStores help reduce landfill-waste by offering the public a way to donate and buy gently-used building materials, appliances and furniture. Twelve Minnesota stores sell goods, using proceeds to build nearby homes.

Minnesota & Climate Change: Do Your Part

Conserve More Energy

Conserve energy in your house:
www.energystar.gov/index.cfm?fuseaction=home_energy_yardstick.showgetstarted

Buy energy-efficient appliances

Walk, bike, carpool and take public transit

Eat Local

Plant a garden

Buy local! *www3.mda.state.mn.us/mngrown*

Compost waste in your backyard

Make Yourself Resilient

Prepare for extreme weather: *www.health.state.mn.us/oep/prepare*

Learn about how climate could be impacting your health:
www.health.state.mn.us/divs/climatechange

Educate Yourself

Learn more about climate change: *nca2014.globalchange.gov*

Watch this video: *www.health.state.mn.us/divs/climatechange/climatevideo.html*

Start Climate Conversations

Talk with others about climate risks and how you use energy and natural resources

Contact your elected officials to find out what they are doing

Protect Your Natural Resources

Conserve water: *www.metrocouncil.org/Wastewater-Water/Planning/Water-Supply-Planning/Water-Conservation-Toolbox-Customers.aspx*

Learn about recycling: *www.rethinkrecycling.com and recyclemoreminnesota.org*

Plant trees and native plants in your community

Credits

This report was developed by the Minnesota Environmental Quality Board (EQB), with contributions from the Interagency Climate Adaptation Team and EQB partner agencies. Funding was provided by the McKnight Foundation.

EQB Partner Agencies

- Board of Water and Soil Resources
- Department of Administration
- Department of Agriculture
- Department of Commerce
- Department of Employment and Economic Development
- Department of Health
- Department of Natural Resources
- Department of Transportation
- Metropolitan Council
- Pollution Control Agency

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About the EQB

Comprised of five citizens and the leaders of nine state agencies to develop policies, the EQB creates long-range plans and reviews proposed projects that significantly influence Minnesota's environment.

Start the Climate Change Conversation!

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08-2014

Minnesota and Climate Change:
How Would You Start The Conversation?

Climate Change Impacts in the United States

CHAPTER 18
MIDWEST

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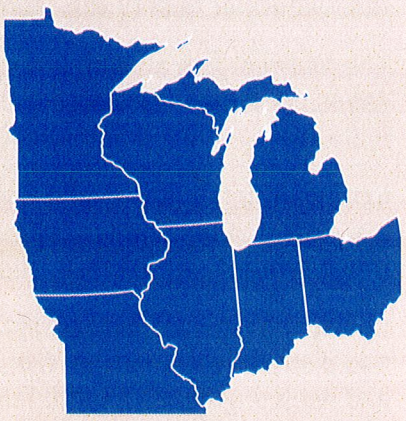

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On the Web: http://nca2014.globalchange.gov/report/regions/midwest

INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

18 MIDWEST

Key Messages

1. **In the next few decades, longer growing seasons and rising carbon dioxide levels will increase yields of some crops, though those benefits will be progressively offset by extreme weather events. Though adaptation options can reduce some of the detrimental effects, in the long term, the combined stresses associated with climate change are expected to decrease agricultural productivity.**
2. **The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward. The role of the region's forests as a net absorber of carbon is at risk from disruptions to forest ecosystems, in part due to climate change.**
3. **Increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality will increase public health risks.**
4. **The Midwest has a highly energy-intensive economy with per capita emissions of greenhouse gases more than 20% higher than the national average. The region also has a large and increasingly utilized potential to reduce emissions that cause climate change.**
5. **Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.**
6. **Climate change will exacerbate a range of risks to the Great Lakes, including changes in the range and distribution of certain fish species, increased invasive species and harmful blooms of algae, and declining beach health. Ice cover declines will lengthen the commercial navigation season.**

The Midwest has a population of more than 61 million people (about 20% of the national total) and generates a regional gross domestic product of more than $2.6 trillion (about 19% of the national total).[1] The Midwest is home to expansive agricultural lands, forests in the north, the Great Lakes, substantial industrial activity, and major urban areas, including eight of the nation's 50 most populous cities. The region has experienced shifts in population, socioeconomic changes, air and water pollution, and landscape changes, and exhibits multiple vulnerabilities to both climate variability and climate change.

In general, climate change will tend to amplify existing climate-related risks from climate to people, ecosystems, and infrastructure in the Midwest (Ch. 10: Energy, Water, and Land). Direct effects of increased heat stress, flooding, drought, and late spring freezes on natural and managed ecosystems may be multiplied by changes in pests and disease prevalence, increased competition from non-native or opportunistic native species, ecosystem disturbances, land-use change, landscape fragmentation, atmospheric pollutants, and economic shocks such as crop failures or reduced yields due to extreme weather events. These added stresses, when taken collectively, are projected to alter the ecosystem and socioeconomic patterns and processes in ways that most people in the region would consider detrimental. Much of the region's fisheries, recreation, tourism, and commerce depend on the Great Lakes and expansive northern forests, which already face pollution and invasive species pressure that will be exacerbated by climate change.

Most of the region's population lives in cities, which are particularly vulnerable to climate change related flooding and life-threatening heat waves because of aging infrastructure and other factors. Climate change may also augment or intensify other stresses on vegetation encountered in urban environments, including increased atmospheric pollution, heat island effects, a highly variable water cycle, and frequent exposure to new pests and diseases. Some cities in the region are already engaged in the process of capacity building or are actively building resilience to the threats posed by climate change. The region's highly energy-intensive economy emits a disproportionately large amount of the gases responsible for warming

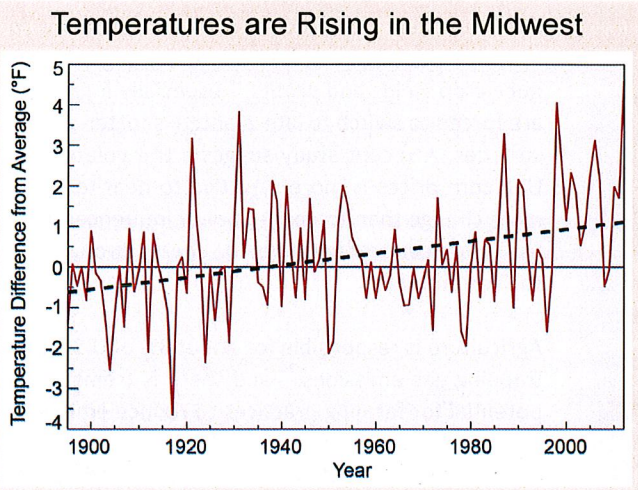


Figure 18.1. Annual average temperatures (red line) across the Midwest show a trend towards increasing temperature. The trend (dashed line) calculated over the period 1895-2012 is equal to an increase of 1.5°F. (Figure source: updated from Kunkel et al. 2013[4]).

the climate (called greenhouse gases or heat-trapping gases). But as discussed below, it also has a large and increasingly realized potential to reduce these emissions.

The rate of warming in the Midwest has markedly accelerated over the past few decades. Between 1900 and 2010, the average Midwest air temperature increased by more than 1.5°F (Figure 18.1). However, between 1950 and 2010, the average temperature increased twice as quickly, and between 1980 and 2010, it increased three times as quickly as it did from 1900 to 2010.[1] Warming has been more rapid at night and during winter. These trends are consistent with expectations of increased concentrations of heat-trapping gases and observed changes in concentrations of certain particles in the atmosphere.[1,2]

The amount of future warming will depend on changes in the atmospheric concentration of heat-trapping gases. Projections for regionally averaged temperature increases by the middle of the century (2046-2065) relative to 1979-2000 are approximately 3.8°F for a scenario with substantial emissions reductions (B1) and 4.9°F with continued growth in global emissions (A2). The projections for the end of the century (2081-2100) are approximately 5.6°F for the lower emissions scenario and 8.5°F for the higher emissions scenario (see Ch. 2: Our Changing Climate, Key Message 3).[3]

In 2011, 11 of the 14 U.S. weather-related disasters with damages of more than $1 billion affected the Midwest.[5] Several types of extreme weather events have already increased in frequency and/or intensity due to climate change, and further increases are projected (Ch. 2: Our Changing Climate, Key Message 7).[6]

Key Message 1: Impacts to Agriculture

In the next few decades, longer growing seasons and rising carbon dioxide levels will increase yields of some crops, though those benefits will be progressively offset by extreme weather events. Though adaptation options can reduce some of the detrimental effects, in the long term, the combined stresses associated with climate change are expected to decrease agricultural productivity.

Agriculture dominates Midwest land use, with more than two-thirds of land designated as farmland.[3] The region accounts for about 65% of U.S. corn and soybean production,[7] mostly from non-irrigated lands.[1] Corn and soybeans constitute 85% of Midwest crop receipts, with high-value crops such as fruits and vegetables making up most of the remainder.[8] Corn and soybean yields increased markedly (by a factor of more than 5) over the last century largely due to technological innovation, but are still vulnerable to year-to-year variations in weather conditions.[9]

The Midwest growing season lengthened by almost two weeks since 1950, due in large part to earlier occurrence of the last spring freeze.[10] This trend is expected to continue,[3,11] though the potential agricultural consequences are complex and vary by crop. For corn, small long-term average temperature increases will shorten the duration of reproductive development, leading to yield declines,[12] even when offset by carbon dioxide (CO_2) stimulation.[13] For soybeans, yields have a two in three chance of increasing early in this century due to CO_2 fertilization, but these increases are projected to be offset later in the century by higher temperature stress[14] (see Figure 18.2 for projections of increases in the frost-free season length and the number of summer days with temperatures over 95°F).

Future crop yields will be more strongly influenced by anomalous weather events than by changes in average temperature or annual precipitation (Ch. 6: Agriculture). Cold injury due to a freeze event after plant budding can decimate fruit crop production,[15] as happened in 2002, and again in 2012, to Michigan's $60 million tart cherry crop. Springtime cold air outbreaks (at least two consecutive days during which the daily average surface air temperature is below 95% of the simulated average wintertime surface air temperature) are projected to continue to occur throughout this century.[16] As a result, increased productivity of some crops due to higher temperatures, longer growing seasons, and elevated CO_2 concentrations could be offset by increased freeze damage.[17] Heat waves during pol-

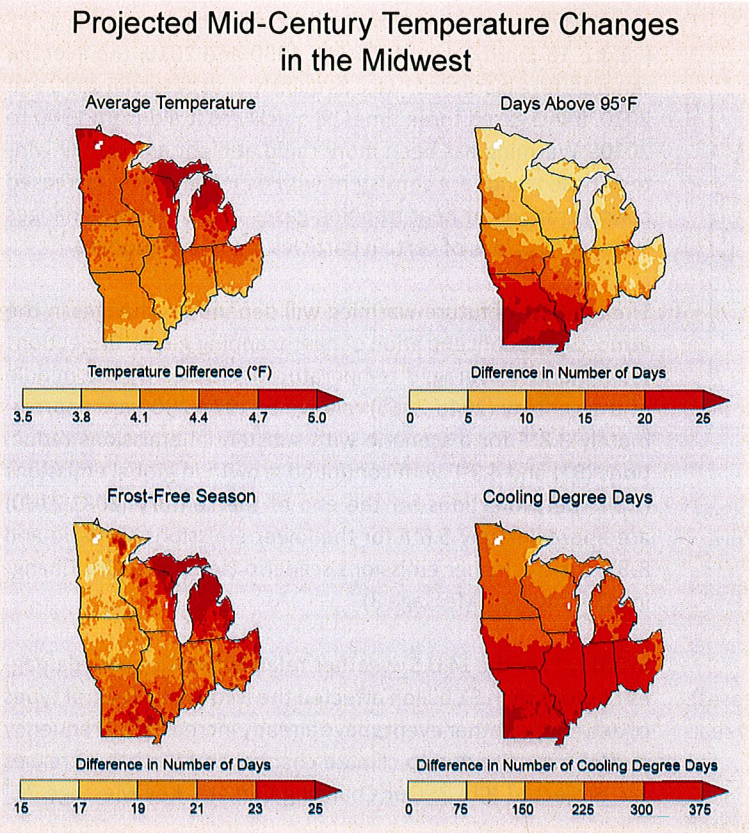


Figure 18.2. Projected increase in annual average temperatures (top left) by mid-century (2041-2070) as compared to the 1971-2000 period tell only part of the climate change story. Maps also show annual projected increases in the number of the hottest days (days over 95°F, top right), longer frost-free seasons (bottom left), and an increase in cooling degree days (bottom right), defined as the number of degrees that a day's average temperature is above 65°F, which generally leads to an increase in energy use for air conditioning. Projections are from global climate models that assume emissions of heat-trapping gases continue to rise (A2 scenario). (Figure source: NOAA NCDC / CICS-NC).

lination of field crops such as corn and soybean also reduce yields (Figure 18.3).[12] Wetter springs may reduce crop yields and profits,[18] especially if growers are forced to switch to late-planted, shorter-season varieties. A recent study suggests the volatility of U.S. corn prices is more sensitive to near-term climate change than to energy policy influences or to use of agricultural products for energy production, such as biofuel.[19]

Agriculture is responsible for about 8% of U.S. heat-trapping gas emissions,[20] and there is tremendous potential for farming practices to reduce emissions or store more carbon in soil.[21] Although large-scale agriculture in the Midwest historically led to decreased carbon in soils, higher crop residue inputs and adoption of different soil management techniques have reversed this trend. Other techniques, such as planting cover crops and no-till soil management, can further increase CO_2 uptake and reduce energy use.[22,23] Use of agricultural best management practices can also improve water quality by reducing the loss of sediments and nutrients from farm fields. Methane released from animals and their wastes can be reduced by altered diets and methane capture systems, and nitrous oxide production can be reduced by judicious fertilizer use[24] and improved waste handling.[21] In addition, if biofuel crops are grown sustainably,[25] they offer emissions reduction opportunities by substituting for fossil fuel-based energy (Ch. 10: Energy, Water, and Land).

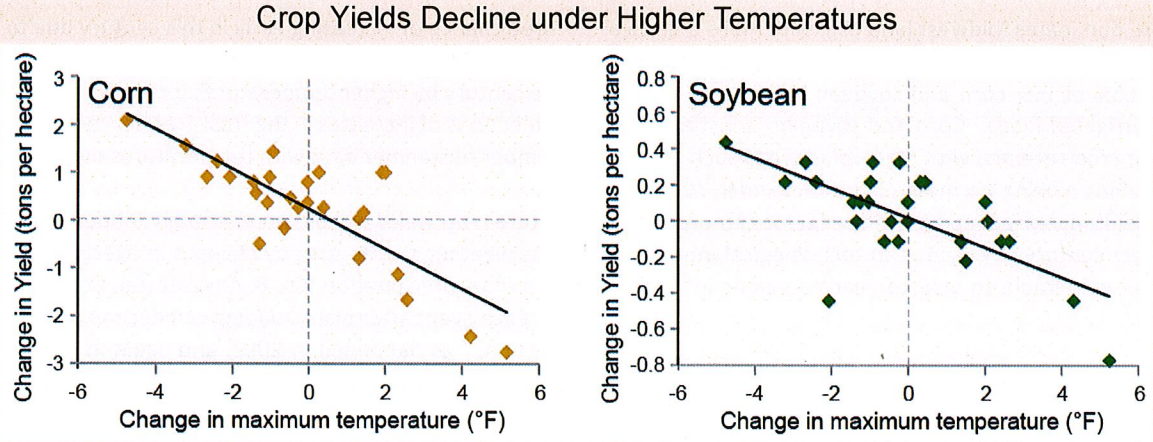


Figure 18.3. Crop yields are very sensitive to temperature and rainfall. They are especially sensitive to high temperatures during the pollination and grain filling period. For example, corn (left) and soybean (right) harvests in Illinois and Indiana, two major producers, were lower in years with average maximum summer (June, July, and August) temperatures higher than the average from 1980 to 2007. Most years with below-average yields are both warmer and drier than normal.[26,27] There is high correlation between warm and dry conditions during Midwest summers[28] due to similar meteorological conditions and drought-caused changes.[29] (Figure source: Mishra and Cherkauer 2010[26]).

Key Message 2: Forest Composition

The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward. The role of the region's forests as a net absorber of carbon is at risk from disruptions to forest ecosystems, in part due to climate change.

The Midwest is characterized by a rich diversity of native species juxtaposed on one of the world's most productive agricultural systems.[30] The remnants of intact natural ecosystems in the region,[31] including prairies, forests, streams, and wetlands, are rich with varied species.[32] The combined effects of climate change, land-use change, and increasing numbers of invasive species are the primary threats to Midwest natural ecosystems.[33] Species most vulnerable to climate change include those that occur in isolated habitats; live near their physiological tolerance limits; have specific habitat requirements, low reproductive rates, or limited dispersal capability; are dependent on interactions with specific other species; and/or have low genetic variability.[34]

Among the varied ecosystems of the region, forest systems are particularly vulnerable to multiple stresses. The habitat ranges of many iconic tree species such as paper birch, quaking aspen, balsam fir, and black spruce are projected to decline substantially across the northern Midwest as they shift northward, while species that are common farther south, including several oaks and pines, expand their ranges northward into the region (Figure 18.4).[35,36] There is considerable variability in the likelihood of a species' habitat changing and the adaptability of the species with regard to climate change.[37] Migration to accommodate changed habitat is expected to be slow for many Midwest species, due to relatively flat topography, high latitudes, and fragmented habitats including the Great Lakes barrier. To reach areas that are 1.8°F cooler, species in mountainous terrains need to shift 550 feet higher in altitude (which can be achieved in only a few miles), whereas species in flat terrain like the Midwest must move as much as 90 miles north to reach a similarly cooler habitat.[38]

Although global forests currently capture and store more carbon each year than they emit,[39] the ability of forests to act as large, global carbon absorbers ("sinks") may be reduced by projected increased disturbances from insect outbreaks,[40] forest fire,[41] and drought,[42] leading to increases in tree mortality and carbon emissions. Some regions may even shift from being a carbon sink to being an atmospheric carbon dioxide source,[43,44] though large uncertainties exist, such as whether projected disturbances to forests will be chronic or episodic.[45] Midwest forests are more resilient to forest carbon losses than most western forests because of relatively high moisture availability, greater nitrogen deposition (which tends to act as a fertilizer), and lower wildfire risk.[43,46]

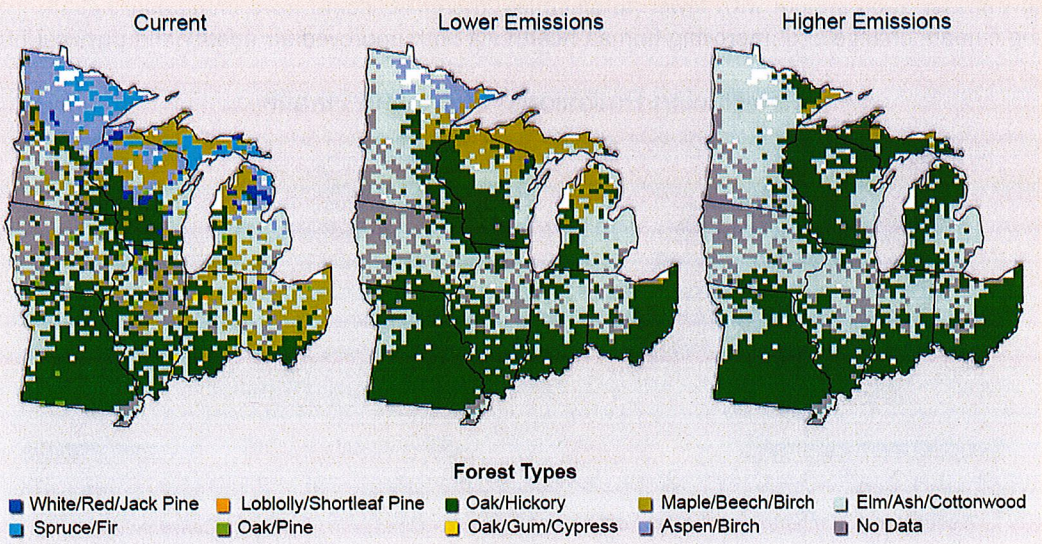


Figure 18.4. As climate changes, species can often adapt by changing their ranges. Maps show current and projected future distribution of habitats for forest types in the Midwest under two emissions scenarios, a lower scenario that assumes reductions in heat-trapping gas emissions (B1), and a very high scenario that assumes continued increases in emissions (A1FI). Habitats for white/red/jack pine, maple/beech/birch, spruce/fir, and aspen/birch forests are projected to greatly decline from the northern forests, especially under higher emissions scenarios, while various oak forest types are projected to expand.[37] While some forest types may not remain dominant, they will still be present in reduced quantities. Therefore, it is more appropriate to assess changes on an individual species basis, since all species within a forest type will not exhibit equal responses to climate change. (Figure source: Prasad et al. 2007[37]).

Key Message 3: Public Health Risks

Increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality will increase public health risks.

The frequency of major heat waves in the Midwest has increased over the last six decades.[47] For the United States, mortality increases 4% during heat waves compared with non-heat wave days.[48] During July 2011, 132 million people across the U.S. were under a heat alert – and on July 20 of that year, the majority of the Midwest experienced temperatures in excess of 100°F. Heat stress is projected to increase as a result of both increased summer temperatures and humidity.[49,50] One study projected an increase of between 166 and 2,217 excess deaths per year from heat wave-related mortality in Chicago alone by 2081-2100.[51] The lower number assumes a climate scenario with significant reductions in emissions of greenhouse gases (B1), while the upper number assumes a scenario under which emissions continue to increase (A2). These projections are significant when compared to recent Chicago heat waves, where 114 people died from the heat wave of 1999 and about 700 died from the heat wave of 1995.[52] Heat response plans and early warning systems save lives, and from 1975 to 2004, mortality rates per heat event declined.[53] However, many municipalities lack such plans.[54]

More than 20 million people in the Midwest experience air quality that fails to meet national ambient air quality standards.[1] Degraded air quality due to human-induced emissions[55] and increased pollen season duration[56] are projected to be amplified with higher temperatures,[57] and pollution and pollen exposures, in addition to heat waves, can harm human health (Ch. 9: Human Health). Policy options exist (for example, see "Alternative Transportation Options Create Multiple Benefits") that could reduce emissions of both heat-trapping gases and other air pollutants, yielding benefits for human health and fitness. Increased temperatures and changes in precipitation patterns could also increase the vulnerability of Midwest residents to diseases carried by insects and rodents (Ch. 9: Human Health).[58]

ALTERNATIVE TRANSPORTATION OPTIONS CREATE MULTIPLE BENEFITS

The transportation sector produces one-third of U.S. greenhouse gas emissions, and automobile exhaust also contains precursors to fine particulate matter ($PM_{2.5}$) and ground-level ozone (O_3), which pose threats to public health. Adopting a low-carbon transportation system with fewer automobiles, therefore, could have immediate health "co-benefits" of both reducing climate change and improving human health via both improved air quality and physical fitness.

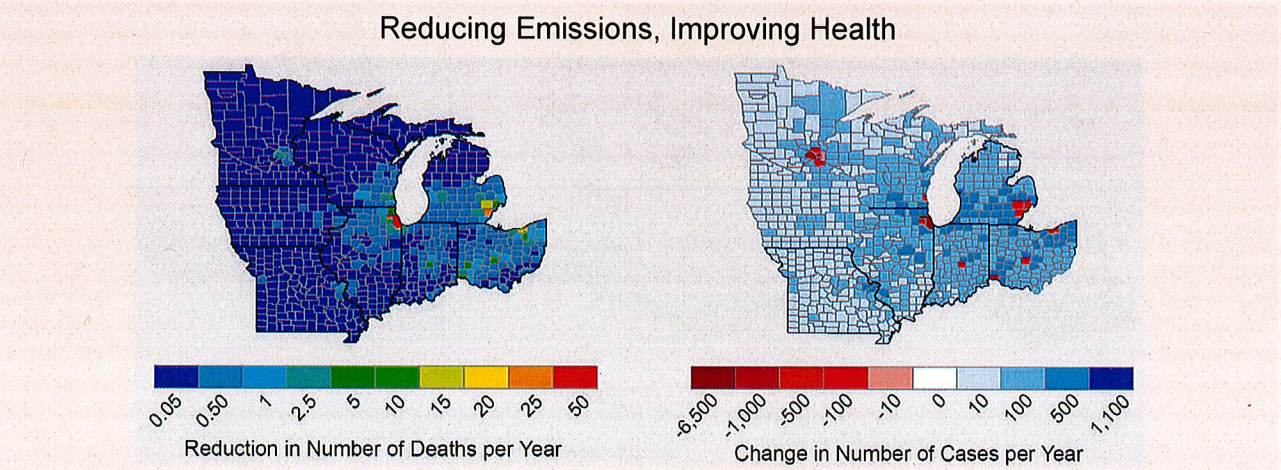


Figure 18.5. Annual reduction in the number of premature deaths (left) and annual change in the number of cases with acute respiratory symptoms (right) due to reductions in particulate matter and ozone caused by reducing automobile exhaust. The maps project health benefits if automobile trips shorter than five miles (round-trip) were eliminated for the 11 largest metropolitan areas in the Midwest. Making 50% of these trips by bicycle just during four summer months would save 1,295 lives and yield savings of more than $8 billion per year from improved air quality, avoided mortality, and reduced health care costs for the upper Midwest alone. (Figure source: Grabow et al. 2012; reproduced with permission from Environmental Health Perspectives[59]).

Key Message 4: Fossil-Fuel Dependent Electricity System

The Midwest has a highly energy-intensive economy with per capita emissions of greenhouse gases more than 20% higher than the national average. The region also has a large and increasingly utilized potential to reduce emissions that cause climate change.

The Midwest is a major exporter of electricity to other U.S. regions and has a highly energy-intensive economy (Ch. 10: Energy, Water, and Land, Figure 10.4). Energy use per dollar of gross domestic product is approximately 20% above the national average, and per capita greenhouse gas emissions are 22% higher than the national average due, in part, to the reliance on fossil fuels, particularly coal for electricity generation.[1] A large range in seasonal air temperature causes energy demand for both heating and cooling, with the highest demand for winter heating. The demand for heating in major midwestern cities is typically five to seven times that for cooling,[1] although this is expected to shift as a result of longer summers, more frequent heat waves, and higher humidity, leading to an increase in the number of cooling degree days. This increased demand for cooling by the middle of this century is projected to exceed 10 gigawatts (equivalent to at least five large conventional power plants), requiring more than $6 billion in infrastructure investments.[60] Further, approximately 95% of the electrical generating infrastructure in the Midwest is susceptible to decreased efficiency due to higher temperatures.[60]

Climate change presents the Midwest's energy sector with a number of challenges, in part because of its current reliance on coal-based electricity[1] and an aging, less-reliable electric distribution grid[61] that will require significant reinvestment even without additional adaptations to climate change.[62]

Increased use of natural gas in the Midwest has the potential to reduce emissions of greenhouse gases. The Midwest also has potential to produce energy from zero- and low-carbon sources, given its wind, solar, and biomass resources, and potential for expanded nuclear power. The Midwest does not have the highest solar potential in the country (that is found in the Southwest), but its potential is nonetheless vast, with some parts of the Midwest having as good a solar resource as Florida.[63] More than one-quarter of national installed wind energy capacity, one-third of biodiesel capacity, and more than two-thirds of ethanol production are located in the Midwest (see also Ch. 4: Energy and Ch. 10: Energy, Water, and Land).[1] Progress toward increasing renewable energy is hampered by electricity prices that are distorted through a mix of direct and indirect subsidies and unaccounted-for costs for conventional energy sources.[64]

Key Message 5: Increased Rainfall and Flooding

Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.

Precipitation in the Midwest is greatest in the east, declining towards the west. Precipitation occurs about once every seven days in the western part of the region and once every three days in the southeastern part.[65] The 10 rainiest days can contribute as much as 40% of total precipitation in a given year.[65] Generally, annual precipitation increased during the past century (by up to 20% in some locations), with much of the increase driven by intensification of the heaviest rainfalls.[65,66] This tendency towards more intense precipitation events is projected to continue in the future.[67]

Model projections for precipitation changes are less certain than those for temperature.[3,4] Under a higher emissions scenario (A2), global climate models (GCMs) project average winter and spring precipitation by late this century (2071-2099) to increase 10% to 20% relative to 1971-2000, while changes in summer and fall are not expected to be larger than natural variations. Projected changes in annual precipitation show increases larger than natural variations in the north and smaller in the south (Ch. 2: Our Changing Climate, Key Message 5).[4] Regional climate models (RCMs) using the same emissions scenario also project increased spring precipitation (9% in 2041-2062 relative to 1979-2000) and decreased summer precipitation (by an average of about 8% in 2041-2062 relative to 1979-2000) particularly in the southern portions of the Midwest.[3] Increases in the frequency and intensity of extreme precipitation are projected across the entire region in both GCM and RCM simulations (Figure 18.6), and these increases are generally larger than the projected changes in average precipitation.[3,4]

Flooding can affect the integrity and diversity of aquatic ecosystems. Flooding also causes major human and economic consequences by inundating urban and agricultural land and by disrupting navigation in the region's roads, rivers, and reservoirs (see Ch. 5: Transportation, Ch. 9: Human Health, and Ch. 11: Urban). For example, the 2008 flooding in the Midwest caused 24 deaths, $15 billion in losses via reduced agricultural yields, and closure of key transportation routes.[1] Water infrastructure for flood control, navigation, and other purposes is susceptible to climate change impacts and other forces because the de-

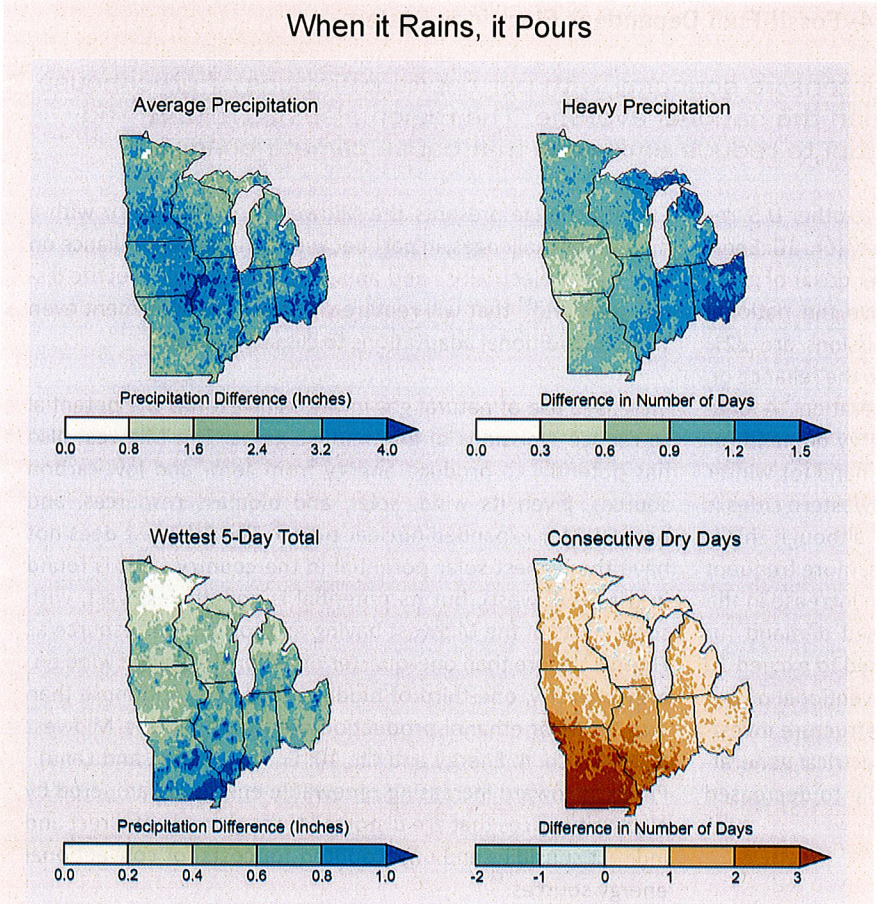


Figure 18.6. Precipitation patterns affect many aspects of life, from agriculture to urban storm drains. These maps show projected changes for the middle of the current century (2041-2070) relative to the end of the last century (1971-2000) across the Midwest under continued emissions (A2 scenario). Top left: the changes in total annual average precipitation. Across the entire Midwest, the total amount of water from rainfall and snowfall is projected to increase. Top right: increase in the number of days with very heavy precipitation (top 2% of all rainfalls each year). Bottom left: increases in the amount of rain falling in the wettest 5-day period over a year. Both (top right and bottom left) indicate that heavy precipitation events will increase in intensity in the future across the Midwest. Bottom right: change in the average maximum number of consecutive days each year with less than 0.01 inches of precipitation. An increase in this variable has been used to indicate an increase in the chance of drought in the future. (Figure source: NOAA NCDC / CICS-NC).

signs are based upon historical patterns of precipitation and streamflow, which are no longer appropriate guides.

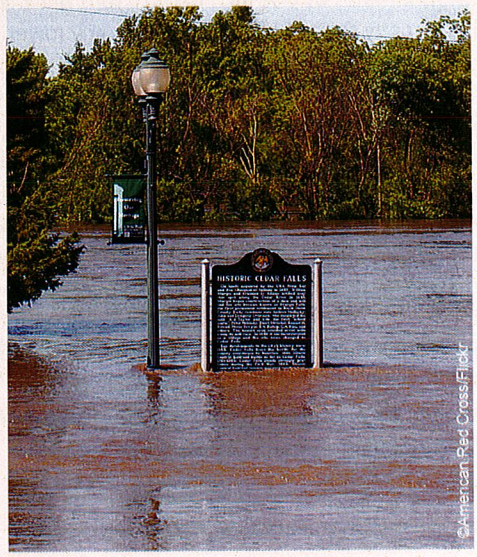
Snowfall varies across the region, comprising less than 10% of total precipitation in the south, to more than half in the north, with as much as two inches of water available in the snowpack at the beginning of spring melt in the northern reaches of the river basins.[68] When this amount of snowmelt is combined with heavy rainfall, the resulting flooding can be widespread and catastrophic (see "Cedar Rapids: A Tale of Vulnerability and Response").[69] Historical observations indicate declines in the frequency of high magnitude snowfall years over much of the Midwest,[70] but an increase in lake effect snowfall.[71] These divergent trends and their inverse relationships with air temperatures make overall projections of regional impacts of the associated snowmelt extremely difficult. Large-scale flooding can also occur due to extreme precipitation in the absence of snowmelt (for example, Rush Creek and the Root River, Minnesota, in August 2007 and multiple rivers in southern Minnesota in September 2010).[72] These warm-season events are projected to increase in magnitude. Such events tend to be more regional and less likely to cover as large an area as those that occur in spring, in part because soil water storage capacity is typically much greater during the summer.

Changing land use and the expansion of urban areas are reducing water infiltration into the soil and increasing surface runoff. These changes exacerbate impacts caused by increased precipitation intensity. Many major Midwest cities are served by combined storm and sewage drainage systems. As surface area has been increasingly converted to impervious surfaces (such as asphalt) and extreme precipitation events have intensified, combined sewer overflow has degraded water quality, a phenomenon expected to continue to worsen with increased urbanization and climate change.[75] The U.S. Environmental Protection Agency (EPA) estimates there are more than 800 billion gallons of untreated combined sewage released into the nation's waters annually.[76] The Great Lakes, which provide drinking water to more than 40 million people and are home to more than 500 beaches,[75] have been subject to recent sewage overflows. For example, stormwater across the city of Milwaukee recently showed high human fecal pathogen levels at all 45 outflow locations, indicating widespread sewage contamination.[77] One study estimated that increased storm events will lead to an increase of up to 120% in combined sewer overflows into Lake Michigan by 2100 under a very high emissions scenario (A1FI),[75] leading to additional human health issues and beach closures. Municipalities may be forced to invest in new infrastructure to protect human health and water quality in the Great Lakes, and local communities could face tourism losses from fouled nearshore regions.

Increased precipitation intensity also increases erosion, damaging ecosystems and increasing delivery of sediment and subsequent loss of reservoir storage capacity. Increased storm-induced agricultural runoff and rising water temperatures

CEDAR RAPIDS: A TALE OF VULNERABILITY AND RESPONSE

Cedar Rapids, Des Moines, Iowa City, and Ames, Iowa, have all suffered multi-million-dollar losses from floods since 1993. In June 2008, a record flood event exceeded the once-in-500-year flood level by more than 5 feet, causing $5 to $6 billion in damages from flooding, or more than $40,000 per resident of the city of Cedar Rapids.[73] The flood inundated much of the downtown, damaging more than 4,000 structures, including 80% of government offices, and displacing 25,000 people.[74] The record flood at Cedar Rapids was the result of low reservoir capacity and extreme rainfall on soil already saturated from unusually wet conditions. Rainfall amounts comparable to those in 1993 (8 inches over two weeks) overwhelmed a flood control system designed largely for a once-in-100-year flood event. Such events are consistent with observations and projections of wetter springs and more intense precipitation events (see Figure 18.6). With the help of more than $3 billion in funding from the federal and state government, Cedar Rapids is recovering and has taken significant steps to reduce future flood damage, with buyouts of more than 1,000 properties, and numerous buildings adapted with flood protection measures.



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have increased non-point source pollution problems in recent years.[78] This has led to increased phosphorus and nitrogen loading, which in turn is contributing to more and prolonged occurrences of low-oxygen "dead zones" and to harmful, lengthy, and dense algae growth in the Great Lakes and other Midwest water bodies.[79] (Such zones and their causes are also discussed in Ch. 25: Coasts, Ch. 15: Biogeochemical Cycles, and Ch. 3: Water, Key Message 6). Watershed planning can be used to reduce water quantity and quality problems due to changing climate and land use.

While there was no apparent change in drought duration in the Midwest region as a whole over the past century,[80] the average number of days without precipitation is projected to increase in the future. This could lead to agricultural drought and suppressed crop yields.[9] This would also increase thermoelectric power plant cooling water temperatures and decrease cooling efficiency and plant capacity because of the need to avoid discharging excessively warm water (see also Ch. 4: Energy, and Ch. 10: Energy, Water, and Land).[60]

Key Message 6: Increased Risks to the Great Lakes

Climate change will exacerbate a range of risks to the Great Lakes, including changes in the range and distribution of certain fish species, increased invasive species and harmful blooms of algae, and declining beach health. Ice cover declines will lengthen the commercial navigation season.

The Great Lakes, North America's largest freshwater feature, have recently recorded higher water temperatures and less ice cover as a result of changes in regional climate (see also Ch. 2: Our Changing Climate, Key Message 11). Summer surface water temperatures in Lakes Huron increased 5.2°F and in Lake Ontario, 2.7°F, between 1968 and 2002,[81] with smaller increases in Lake Erie.[81,82] Due to the reduction in ice cover, the temperature of surface waters in Lake Superior during the summer increased 4.5°F, twice the rate of increase in air temperature.[83] These lake surface temperatures are projected to rise by as much as 7°F by 2050 and 12.1°F by 2100.[84,85] Higher temperatures, increases in precipitation, and lengthened growing seasons favor production of blue-green and toxic algae that can harm fish, water quality, habitats, and aesthetics,[79,84,86] and could heighten the impact of invasive species already present.[87]

In the Great Lakes, the average annual maximum ice coverage during 2003-2013 was less than 43% compared to the 1962-2013 average of 52%,[88] lower than any other decade during the period of measurements (Figure 18.7), although there is substantial variability from year to year. During the 1970s, which included several extremely cold winters, maximum ice coverage averaged 67%. Less ice, coupled with more frequent and intense storms (as indicated by some analyses of historical wind speeds),[89] leaves shores vulnerable to erosion and flooding and could harm property and fish habitat.[84,90] Reduced ice cover also has the potential to lengthen the shipping season.[91] The navigation season increased by an average of eight days between 1994 and 2011, and the Welland Canal in the St. Lawrence River remained open nearly two weeks longer. Increased shipping days benefit commerce but could also increase shoreline scouring and bring in more invasive species.[91,92]

Changes in lake levels can also influence the amount of cargo that can be carried on ships. On average, a 1000-foot ship sinks into the water by one inch per 270 tons of cargo;[93] thus if a ship is currently limited by water depth, any lowering of lake levels will result in a proportional reduction in the amount of cargo that it can transport to Great Lakes ports. However, current estimates of lake level changes are uncertain, even for continued increases in global greenhouse gas emissions (A2 scenario). The most recent projections suggest a slight decrease or even a small rise in levels.[94] Recent studies have also indicated that earlier approaches to computing evapotranspiration estimates from temperature may have overestimated evaporation losses.[94,95,96,97] The recent studies, along with the large spread in existing modeling results, indicate that projections of Great Lakes water levels represent evolving research and are still subject to considerable uncertainty (see Appendix 3: Climate Science Supplemental Message 8).

Ice Cover in the Great Lakes

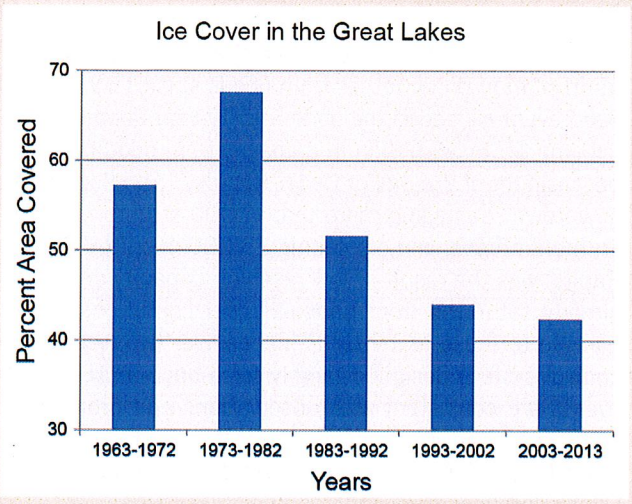

Figure 18.7. Bars show decade averages of annual maximum Great Lakes ice coverage from the winter of 1962-1963, when reliable coverage of the entire Great Lakes began, to the winter of 2012-2013. Bar labels indicate the end year of the winter; for example, 1963-1972 indicates the winter of 1962-1963 through the winter of 1971-1972. The most recent period includes the eleven years from 2003 to 2013. (Data updated from Bai and Wang, 2012[88]).

REFERENCES

1. Pryor, S. C., and R. J. Barthelmie, 2013: Ch. 2: The Midwestern United States: Socio-economic context and physical climate. *Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation*, S. C. Pryor, Ed., Indiana University Press, 12-47.

2. Pan, Z. T., M. Segal, X. Li, and B. Zib, 2009: Ch. 3: Global climate change impact on the Midwestern USA - A summer cooling trend. *Understanding Climate Change: Climate Variability, Predictability and Change in the Midwestern United States*, S. C. Pryor, Ed., Indiana University Press, 29-41.

3. Pryor, S. C., R. J. Barthelmie, and J. T. Schoof, 2013: High-resolution projections of climate impacts for the midwestern USA. *Climate Research* **56,** 61-79, doi:10.3354/cr01143. [Available online at http://www.int-res.com/articles/cr2013/56/c056p061.pdf]

4. Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, S. D. Hilberg, M. S. Timlin, L. Stoecker, N. E. Westcott, and J. G. Dobson, 2013: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 3. Climate of the Midwest U.S. NOAA Technical Report NESDIS 142-3. 103 pp., National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, Washington, D.C. [Available online at http://www.nesdis.noaa.gov/technical_reports/NOAA_NESDIS_Tech_Report_142-3-Climate_of_the_Midwest_U.S.pdf]

5. NOAA, cited 2012: Extreme Weather 2011. National Oceanic and Atmospheric Administration. [Available online at http://www.noaa.gov/extreme2011/]

6. Rahmstorf, S., and D. Coumou, 2011: Increase of extreme events in a warming world. *Proceedings of the National Academy of Sciences*, **108,** 17905-17909, doi:10.1073/pnas.1101766108. [Available online at http://www.pnas.org/content/108/44/17905.full.pdf+html]

7. ERS, cited 2012: Data sets. State fact sheets. U.S. Department of Agriculture, Economic Research Service. [Available online at http://ers.usda.gov/data-products/state-fact-sheets.aspx]

8. National Agricultural Statistics Service, 2012: Crop Production 2011 Summary, 95 pp., U.S. Department of Agriculture. [Available online at http://usda01.library.cornell.edu/usda/nass/CropProdSu//2010s/2012/CropProdSu-01-12-2012.pdf]

9. Niyogi, D. M., and V. Mishra, 2013: Ch. 5: Climate - agriculture vulnerability assessment for the Midwestern United States. *Climate Change in the Midwest: Impacts, Risks, Vulnerability, and Adaptation*, S. C. Pryor, Ed., Indiana University Press 69-81.

10. Schoof, J. T., 2009: Ch. 4: Historical and projected changes in the length of the frost-free season. *Understanding Climate Change: Climate Variability, Predictability and Change in the Midwestern United States*, S. C. Pryor, Ed., Indiana University Press, 42-54.

11. Mearns, L. O., R. Arritt, S. Biner, M. S. Bukovsky, S. Stain, S. Sain, D. Caya, J. J. Correia, D. Flory, W. Gutowski, E. S. Takle, R. Jones, R. Leung, W. Moufouma-Okia, L. McDaniel, A. M. B. Nunes, Y. Qian, J. Roads, L. Sloan, and M. Snyder, 2012: The North American regional climate change assessment program: Overview of phase I results. *Bulletin of the American Meteorological Society*, **93,** 1337-1362, doi:10.1175/BAMS-D-11-00223.1.

12. Hatfield, J. L., K. J. Boote, B. A. Kimball, L. H. Ziska, R. C. Izaurralde, D. Ort, A. M. Thomson, and D. Wolfe, 2011: Climate impacts on agriculture: Implications for crop production. *Agronomy Journal*, **103,** 351-370, doi:10.2134/agronj2010.0303.

13. Leakey, A. D. B., 2009: Rising atmospheric carbon dioxide concentration and the future of C_4 crops for food and fuel. *Proceedings of the Royal Society B: Biological Sciences*, **276,** 2333-2343, doi:10.1098/rspb.2008.1517. [Available online at http://rspb.royalsocietypublishing.org/content/276/1666/2333.full.pdf+html]

    Sage, R. F., and D. S. Kubien, 2003: Quo vadis C_4? An ecophysiological perspective on global change and the future of C_4 plants. *Photosynthesis Research*, **77,** 209-225, doi:10.1023/a:1025882003661.

14. Lobell, D. B., and C. B. Field, 2007: Global scale climate - crop yield relationships and the impacts of recent warming. *Environmental Research Letters*, **2**, doi:10.1088/1748-9326/2/1/014002. [Available online at http://iopscience.iop.org/1748-9326/2/1/014002/pdf/1748-9326_2_1_014002.pdf]

15. Winkler, J. A., J. Andresen, J. Bisanz, G. Guentchev, J. Nugent, K. Primsopa, N. Rothwell, C. Zavalloni, J. Clark, H. K. Min, A. Pollyea, and H. Prawiranta, 2013: Ch. 8: Michigan's tart cherry industry: Vulnerability to climate variability and change. *Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation*, S. C. Pryor, Ed., Indiana University Press, 104-116.

16. Vavrus, S., J. E. Walsh, W. L. Chapman, and D. Portis, 2006: The behavior of extreme cold air outbreaks under greenhouse warming. *International Journal of Climatology*, **26,** 1133-1147, doi:10.1002/joc.1301.

17. Gu, L., P. J. Hanson, W. Mac Post, D. P. Kaiser, B. Yang, R. Nemani, S. G. Pallardy, and T. Meyers, 2008: The 2007 eastern US spring freezes: Increased cold damage in a warming world? *BioScience*, **58,** 253-262, doi:10.1641/b580311. [Available online at http://www.jstor.org/stable/10.1641/B580311]

18. Rosenzweig, C., F. N. Tubiello, R. Goldberg, E. Mills, and J. Bloomfield, 2002: Increased crop damage in the US from excess precipitation under climate change. *Global Environmental Change*, **12,** 197-202, doi:10.1016/S0959-3780(02)00008-0.

19. Diffenbaugh, N. S., T. W. Hertel, M. Scherer, and M. Verma, 2012: Response of corn markets to climate volatility under alternative energy futures. *Nature Climate Change*, **2,** 514-518, doi:10.1038/nclimate1491. [Available online at http://www.nature.com/nclimate/journal/v2/n7/pdf/nclimate1491.pdf]

20. EPA, 2012: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010, 389 pp., U.S. Environmental Protection Agency, Washington, D.C. [Available online at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Annexes.pdf]

21. CAST, 2011: *Carbon Sequestration and Greenhouse Gas Fluxes in Agriculture: Challenges and Opportunities. Task Force Report No.142.* Council for Agricultural Science and Technology 105 pp. [Available online at http://www.cast-science.org/file.cfm/media/news/CAST_TF_Report_142_Interpretive_Sum_EPA290A703478.pdf]

22. Gelfand, I., S. S. Snapp, and G. P. Robertson, 2010: Energy efficiency of conventional, organic, and alternative cropping systems for food and fuel at a site in the U.S. Midwest. *Environmental Science and Technology*, **44,** 4006-4011, doi:10.1021/es903385g.

23. Pan, Z. T., D. Andrade, and N. Gosselin, 2013: Ch. 7: Vulnerability of soil carbon reservoirs in the Midwest to climate change. *Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation*, S. C. Pryor, Ed., Indiana University Press, 92-103.

24. Robertson, G. P., T. W. Bruulsema, R. J. Gehl, D. Kanter, D. L. Mauzerall, C. A. Rotz, and C. O. Williams, 2013: Nitrogen-climate interactions in US agriculture. *Biogeochemistry*, **114,** 41-70, doi:10.1007/s10533-012-9802-4. [Available online at http://link.springer.com/content/pdf/10.1007%2Fs10533-012-9802-4.pdf]

25. Robertson, G. P., V. H. Dale, O. C. Doering, S. P. Hamburg, J. M. Melillo, M. M. Wander, W. J. Parton, P. R. Adler, J. N. Barney, R. M. Cruse, C. S. Duke, P. M. Fearnside, R. F. Follett, H. K. Gibbs, J. Goldemberg, D. J. Mladenoff, D. Ojima, M. W. Palmer, A. Sharpley, L. Wallace, K. C. Weathers, J. A. Wiens, and W. W. Wilhelm, 2008: Agriculture - Sustainable biofuels redux. *Science*, **322,** 49-50, doi:10.1126/science.1161525.

26. Mishra, V., and K. A. Cherkauer, 2010: Retrospective droughts in the crop growing season: Implications to corn and soybean yield in the midwestern United States. *Agricultural and Forest Meteorology*, **150,** 1030-1045, doi:10.1016/j.agrformet.2010.04.002.

27. Changnon, S. A., and D. Winstanley, 1999: *Long-Term Variations in Seasonal Weather Conditions and Their Impacts on Crop Production and Water Resources in Illinois. Water Survey Research Report RR-127.* Illinois State Water Survey, Dept. of Natural Resources. [Available online at http://www.isws.uiuc.edu/pubdoc/RR/ISWSRR-127.pdf]

28. Karl, T. R., B. E. Gleason, M. J. Menne, J. R. McMahon, R. R. Heim, Jr., M. J. Brewer, K. E. Kunkel, D. S. Arndt, J. L. Privette, J. J. Bates, P. Y. Groisman, and D. R. Easterling, 2012: U.S. temperature and drought: Recent anomalies and trends. *Eos, Transactions, American Geophysical Union*, **93,** 473-474, doi:10.1029/2012EO470001. [Available online at http://onlinelibrary.wiley.com/doi/10.1029/2012EO470001/pdf]

29. Kunkel, K. E., 1989: A surface energy budget view of the 1988 midwestern United States drought. *Boundary-Layer Meteorology*, **48,** 217-225, doi:10.1007/BF00158325.

30. Ricketts, T., and M. Imhoff, 2003: Biodiversity, urban areas, and agriculture: Locating priority ecoregions for conservation. *Conservation Ecology*, **8,** 1-15. [Available online at http://www.ecologyandsociety.org/vol8/iss2/art1/]

31. Klopatek, J. M., R. J. Olson, C. J. Emerson, and J. L. Joness, 1979: Land-use conflicts with natural vegetation in the United States. *Environmental Conservation*, **6,** 191-199, doi:10.1017/S0376892900003039.

32. Bischof, M. M., M. A. Hanson, M. R. Fulton, R. K. Kolka, S. D. Sebestyen, and M. G. Butler, 2013: Invertebrate community patterns in seasonal ponds in Minnesota, USA: Response to hydrologic and environmental variability. *Wetlands*, **33,** 245-256, doi:10.1007/s13157-012-0374-9.

Iverson, L., and A. Prasad, 1998: Estimating regional plant biodiversity with GIS modelling. *Diversity and Distributions*, **4,** 49-61, doi:10.1046/j.1472-4642.1998.00007.x. [Available online at http://onlinelibrary.wiley.com/doi/10.1046/j.1472-4642.1998.00007.x/pdf]

Sivicek, V. A., and J. B. Taft, 2011: Functional Group Density as an index for assessing habitat quality in tallgrass prairie. *Ecological Indicators*, **11,** 1251-1258, doi:10.1016/j.ecolind.2011.01.003.

33. Dale, V. H., R. A. Efroymson, and K. L. Kline, 2011: The land use–climate change–energy nexus. *Landscape Ecology*, **26,** 755–773, doi:10.1007/s10980-011-9606-2.

Jenkins, D. G., S. Grissom, and K. Miller, 2003: Consequences of prairie wetland drainage for crustacean biodiversity and metapopulations. *Conservation Biology*, **17,** 158-167, doi:10.1046/j.1523-1739.2003.01450.x. [Available online at http://onlinelibrary.wiley.com/doi/10.1046/j.1523-1739.2003.01450.x/pdf]

34. Brook, B. W., N. S. Sodhi, and C. J. A. Bradshaw, 2008: Synergies among extinction drivers under global change. *Trends in Ecology & Evolution*, **23,** 453-460, doi:10.1016/j.tree.2008.03.011.

Foden, W., G. Mace, J.-C. Vié, A. Angulo, S. Butchart, L. DeVantier, H. Dublin, A. Gutsche, S. Stuart, and E. Turak, 2008: Species susceptibility to climate change impacts. *The 2008 Review of The IUCN Red List of Threatened Species*, J.-C. Vié, C. Hilton-Taylor, and S. N. Stuart, Eds., IUCN.

Parmesan, C., 2006: Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics*, **37,** 637-669, doi:10.1146/annurev.ecolsys.37.091305.110100. [Available online at http://www.jstor.org/stable/pdfplus/30033846.pdf]

35. Hellmann, J. J., K. J. Nadelhoffer, L. R. Iverson, L. H. Ziska, S. N. Matthews, P. Myers, A. M. Prasad, and M. P. Peters, 2010: Climate change impacts on terrestrial ecosystems in the Chicago region. *Great Lakes Research*, **36,** 74-85, doi:10.1016/j.jglr.2009.12.001. [Available online at http://naldc.nal.usda.gov/download/49775/PDF]

Swanston, C. W., M. Janowiak, L. R. Iverson, L. R. Parker, D. J. Mladenoff, L. Brandt, P. Butler, M. St. Pierre, A. M. Prasad, S. Matthews, M. P. Peters, and D. Higgins, 2011: Ecosystem Vulnerability Assessment and Synthesis: A Report From the Climate Change Response Framework Project in Northern Wisconsin. Gen. Tech. Rep. NRS-82, 142 pp., U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. [Available online at http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs82.pdf]

36. Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters, 2008: Estimating potential habitat for 134 eastern US tree species under six climate scenarios. *Forest Ecology and Management*, **254,** 390-406, doi:10.1016/j.foreco.2007.07.023. [Available online at http://nrs.fs.fed.us/pubs/jrnl/2008/nrs_2008_iverson_002.pdf]

37. Prasad, A. M., L. R. Iverson, S. Matthews, and M. Peters, cited 2007: A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [Database]. U.S. Department of Agriculture, Forest Service, Northern Research Station. [Available online at http://www.nrs.fs.fed.us/atlas/tree]

38. Jump, A. S., C. Mátyás, and J. Peñuelas, 2009: The altitude-for-latitude disparity in the range retractions of woody species. *Trends in Ecology & Evolution*, **24,** 694-701, doi:10.1016/j.tree.2009.06.007.

39. Pan, Y., R. A. Birdsey, J. Fang, R. Houghton, P. E. Kauppi, W. A. Kurz, O. L. Phillips, A. Shvidenko, S. L. Lewis, J. G. Canadell, P. Ciais, R. B. Jackson, S. W. Pacala, A. D. McGuire, S. Piao, A. Rautiainen, S. Sitch, and D. Hayes, 2011: A large and persistent carbon sink in the world's forests. *Science*, **333,** 988-993, doi:10.1126/science.1201609. [Available online at http://www.lter.uaf.edu/pdf/1545_Pan_Birdsey_2011.pdf]

40. Bradley, B. A., D. S. Wilcove, and M. Oppenheimer, 2010: Climate change increases risk of plant invasion in the Eastern United States. *Biological Invasions*, **12,** 1855-1872, doi:10.1007/s10530-009-9597-y. [Available online at http://europepmc.org/abstract/AGR/IND44367832/reload=0;jsessionid=geMUvZpMPs0zzRUz8D6h.2]

41. Liu, Y., J. Stanturf, and S. Goodrick, 2010: Trends in global wildfire potential in a changing climate. *Forest Ecology and Management*, **259,** 685-697, doi:10.1016/j.foreco.2009.09.002.

42. Allen, C. D., A. K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D. D. Breshears, E. H. Hogg, P. Gonzalez, R. Fensham, Z. Zhang, J. Castro, N. Demidova, J.-H. Lim, G. Allard, S. W. Running, A. Semerci, and N. Cobb, 2010: A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management*, **259,** 660-684, doi:10.1016/j.foreco.2009.09.001. [Available online at http://www.sciencedirect.com/science/article/pii/S037811270900615X]

43. Birdsey, R., K. Pregitzer, and A. Lucier, 2006: Forest carbon management in the United States: 1600–2100. *Journal of Environmental Quality*, **35,** 1461–1469, doi:10.2134/jeq2005.0162.

Reich, P. B., 2011: Biogeochemistry: Taking stock of forest carbon. *Nature Climate Change*, **1,** 346–347, doi:10.1038/nclimate1233.

44. USFS, 2012: Future of America's forest and rangelands: 2010 Resources Planning Act assessment. General Technical Report WO-87. 198 pp., U.S. Department of Agriculture, U.S. Forest Service, Washington, D.C. [Available online at http://www.fs.fed.us/research/publications/gtr/gtr_wo87.pdf]

45. Vanderwel, M. C., D. A. Coomes, and D. W. Purves, 2013: Quantifying variation in forest disturbance, and its effects on aboveground biomass dynamics, across the eastern United States. *Global Change Biology*, **19,** 1504-1517, doi:10.1111/gcb.12152. [Available online at http://onlinelibrary.wiley.com/doi/10.1111/gcb.12152/pdf]

46. Williams, C. A., G. J. Collatz, J. Masek, and S. N. Goward, 2012: Carbon consequences of forest disturbance and recovery across the conterminous United States. *Global Biogeochemical Cycles*, **26,** GB1005, doi:10.1029/2010gb003947.

47. Luber, G., and M. McGeehin, 2008: Climate change and extreme heat events. *American Journal of Preventive Medicine*, **35,** 429-435, doi:10.1016/j.amepre.2008.08.021. [Available online at http://download.journals.elsevierhealth.com/pdfs/journals/0749-3797/PIIS0749379708006867.pdf]

48. Anderson, G. B., and M. L. Bell, 2011: Heat waves in the United States: Mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. *Environmental Health Perspectives*, **119,** 210-218, doi:10.1289/ehp.1002313.

49. Schoof, J. T., 2013: Ch. 11: Historical and projected changes in human heat stress in the Midwestern United States. *Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation*, S. C. Pryor, Ed., Indiana University Press, 146-157.

50. Rogers, J. C., S. H. Wang, and J. Coleman, 2009: Ch. 5: Long-term Midwestern USA summer equivalent temperature variability. *Understanding Climate Change: Climate Variability, Predictability and Change in the Midwestern United States*, S. C. Pryor, Ed., Indiana University Press, 55-65.

51. Peng, R. D., J. F. Bobb, C. Tebaldi, L. McDaniel, M. L. Bell, and F. Dominici, 2011: Toward a quantitative estimate of future heat wave mortality under global climate change. *Environmental Health Perspectives*, **119,** 701-706, doi:10.1289/ehp.1002430. [Available online at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3094424/]

52. Palecki, M. A., S. A. Changnon, and K. E. Kunkel, 2001: The nature and impacts of the July 1999 heat wave in the midwestern United States: Learning from the lessons of 1995. *Bulletin of the American Meteorological Society*, **82,** 1353-1368, doi:10.1175/1520-0477(2001)082<1353:TNAIOT>2.3.CO;2. [Available online at http://journals.ametsoc.org/doi/pdf/10.1175/1520-0477%282001%29082%3C1353%3ATNAIOT%3E2.3.CO%3B2]

53. Sheridan, S. C., A. J. Kalkstein, and L. S. Kalkstein, 2009: Trends in heat-related mortality in the United States, 1975-2004. *Natural Hazards*, **50,** 145-160, doi:10.1007/s11069-008-9327-2. [Available online at http://www.as.miami.edu/geography/research/climatology/natural_hazards_manuscript.pdf]

54. Weisskopf, M. G., H. A. Anderson, S. Foldy, L. P. Hanrahan, K. Blair, T. J. Torok, and P. D. Rumm, 2002: Heat wave morbidity and mortality, Milwaukee, Wis, 1999 vs 1995: An improved response? *American Journal of Public Health*, **92,** 830-833, doi:10.2105/AJPH.92.5.830. [Available online at http://ajph.aphapublications.org/doi/pdf/10.2105/AJPH.92.5.830]

55. Holloway, T., S. N. Spak, D. Barker, M. Bretl, C. Moberg, K. Hayhoe, J. Van Dorn, and D. Wuebbles, 2008: Change in ozone air pollution over Chicago associated with global climate change. *Journal of Geophysical Research-Atmospheres*, **113,** D22306, doi:10.1029/2007JD009775. [Available online at http://onlinelibrary.wiley.com/doi/10.1029/2007JD009775/pdf]

56. Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M. A. Elder, W. Filley, J. Shropshire, L. B. Ford, C. Hedberg, P. Fleetwood, K. T. Hovanky, T. Kavanaugh, G. Fulford, R. F. Vrtis, J. A. Patz, J. Portnoy, F. Coates, L. Bielory, and D. Frenz, 2011: Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proceedings of the National Academy of Sciences*, **108,** 4248-4251, doi:10.1073/pnas.1014107108. [Available online at http://www.pnas.org/content/108/10/4248.full.pdf+html]

57. Jacob, D. J., and D. A. Winner, 2009: Effect of climate change on air quality. *Atmospheric Environment*, **43,** 51-63, doi:10.1016/j.atmosenv.2008.09.051. [Available online at http://www.sciencedirect.com/science/article/pii/S1352231008008571]

58. Ashley, S. T., and V. Meentemeyer, 2004: Climatic analysis of Lyme disease in the United States. *Climate Research*, **27,** 177-187, doi:10.3354/cr027177.

Ogden, N. H., L. R. Lindsay, G. Beauchamp, D. Charron, A. Maarouf, C. J. O'Callaghan, D. Waltner-Toews, and I. K. Barker, 2004: Investigation of relationships between temperature and developmental rates of tick *Ixodes scapularis* (Acari: Ixodidae) in the laboratory and field. *Journal of Medical Entomology*, **41,** 622-633, doi:10.1603/0022-2585-41.4.622. [Available online at http://www.bioone.org/doi/pdf/10.1603/0022-2585-41.4.622]

Ward, M. P., M. Levy, H. L. Thacker, M. Ash, S. K. L. Norman, G. E. Moore, and P. W. Webb, 2004: Investigation of an outbreak of encephalomyelitis caused by West Nile virus in 136 horses. *JAVMA-Journal of the American Veterinary Medical Association*, **225,** 84-89, doi:10.2460/javma.2004.225.84.

59. Grabow, M. L., S. N. Spak, T. Holloway, B. Stone, Jr. , A. C. Mednick, and J. A. Patz, 2012: Air quality and exercise-related health benefits from reduced car travel in the midwestern United States. *Environmental Health Perspectives*, **120,** 68-76, doi:10.1289/ehp.1103440. [Available online at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3261937/pdf/ehp.1103440.pdf]

60. Gotham, D., J. R. Angel, and S. C. Pryor, 2013: Ch. 12: Vulnerability of the electricity and water sectors to climate change in the Midwest. *Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation*, S. C. Pryor, Ed., Indiana University Press, 192-211.

61. Amin, S. M., 2010: U.S. electrical grid gets less reliable. [Available online at http://spectrum.ieee.org/energy/policy/us-electrical-grid-gets-less-reliable]

62. Midwest Independent Transmission System Operator, 2011: MISO transmission expansion plan 2011, 123 pp. [Available online at https://www.midwestiso.org/Library/Repository/Study/MTEP/MTEP11/MTEP11DraftReport.pdf]

63. World Resources Institute: Power Almanac of the American Midwest. Word Resources Institute and Great Plains Institute. [Available online at http://www.wri.org/tools/mwalmanac/almanac.php#questions]

64. Sovacool, B. K., 2009: Rejecting renewables: The socio-technical impediments to renewable electricity in the United States. *Energy Policy*, **37,** 4500-4513, doi:10.1016/j.enpol.2009.05.073.

65. Pryor, S. C., K. E. Kunkel, and J. T. Schoof, 2009: Ch. 9: Did precipitation regimes change during the twentieth century? *Understanding Climate Change: Climate Variability, Predictability and Change in the Midwestern United States*, Indiana University Press, 100-112.

66. Pryor, S. C., J. A. Howe, and K. E. Kunkel, 2009: How spatially coherent and statistically robust are temporal changes in extreme precipitation in the contiguous USA? *International Journal of Climatology*, **29,** 31-45, doi:10.1002/joc.1696. [Available online at http://onlinelibrary.wiley.com/doi/10.1002/joc.1696/pdf]

Villarini, G., J. A. Smith, M. L. Baeck, R. Vitolo, D. B. Stephenson, and W. F. Krajewski, 2011: On the frequency of heavy rainfall for the Midwest of the United States. *Journal of Hydrology*, **400,** 103-120, doi:10.1016/j.jhydrol.2011.01.027.

67. Schoof, J. T., S. C. Pryor, and J. Suprenant, 2010: Development of daily precipitation projections for the United States based on probabilistic downscaling. *Journal of Geophysical Research*, **115,** 1-13, doi:10.1029/2009JD013030. [Available online at http://geog.siu.edu/pdfFiles/Courses/500/schoof_et_al_2010.pdf]

68. Buan, S. D., cited 2012: Frequency mapping of maximum water equivalent of march snow cover over Minnesota and the eastern Dakotas, NWS CR Tech Memo CR-113, 28. National Weather Service [Available online at http://www.crh.noaa.gov/crh/?n=tm-113]

69. Peterson, T. C., R. R. Heim, R. Hirsch, D. P. Kaiser, H. Brooks, N. S. Diffenbaugh, R. M. Dole, J. P. Giovannettone, K. Guirguis, T. R. Karl, R. W. Katz, K. Kunkel, D. Lettenmaier, G. J. McCabe, C. J. Paciorek, K. R. Ryberg, S. Schubert, V. B. S. Silva, B. C. Stewart, A. V. Vecchia, G. Villarini, R. S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C. A. Woodhouse, and D. Wuebbles, 2013: Monitoring and understanding changes in heat waves, cold waves, floods and droughts in the United States: State of knowledge. *Bulletin American Meteorological Society*, **94,** 821-834, doi:10.1175/BAMS-D-12-00066.1. [Available online at http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00066.1]

70. Kunkel, K. E., M. A. Palecki, L. Ensor, D. Easterling, K. G. Hubbard, D. Robinson, and K. Redmond, 2009: Trends in twentieth-century U.S. extreme snowfall seasons. *Journal of Climate*, **22,** 6204-6216, doi:10.1175/2009JCLI2631.1. [Available online at http://journals.ametsoc.org/doi/pdf/10.1175/2009JCLI2631.1]

71. Kristovich, D. A. R., 2009: Ch. 21: Climate sensitivity of Great Lakes-generated weather systems. *Understanding Climate Change: Climate Variability, Predictability and Change in the Midwestern United States*, S. C. Pryor, Ed., Indiana University Press, 236-250.

72. Ellison, C. A., C. A. Sanocki, D. L. Lorenz, G. B. Mitton, and G. A. Kruse, 2011: Floods of September 2010 in Southern Minnesota, U.S. Geological Survey Scientific Investigations Report 2011-5045, 37 pp., The 2011 Flood in the Mississippi and Tributaries Project, USACE Mississippi River Commission. [Available online at http://pubs.usgs.gov/sir/2011/5045/pdf/sir2011-5045.pdf]

73. Budikova, D., J. Coleman, S. Strope, and A. Austin, 2010: Hydroclimatology of the 2008 Midwest floods. *Water Resources Research*, **46,** W12524, doi:10.1029/2010WR009206. [Available online at http://onlinelibrary.wiley.com/doi/10.1029/2010WR009206/pdf]

74. Mutel, C. F., 2010: *A Watershed Year: Anatomy of the Iowa Floods of 2008*. University of Iowa Press, 284 pp.

75. Patz, J. A., S. J. Vavrus, C. K. Uejio, and S. L. McLellan, 2008: Climate change and waterborne disease risk in the Great Lakes region of the US. *American Journal of Preventive Medicine*, **35,** 451-458, doi:10.1016/j.amepre.2008.08.026. [Available online at http://www.ajpmonline.org/article/S0749-3797(08)00702-2/fulltext]

76. McLellan, S. L., E. J. Hollis, M. M. Depas, M. Van Dyke, J. Harris, and C. O. Scopel, 2007: Distribution and fate of *Escherichia coli* in Lake Michigan following contamination with urban stormwater and combined sewer overflows. *Journal of Great Lakes Research*, **33,** 566-580, doi:10.3394/0380-1330(2007)33[566:DAFOEC]2.0.CO;2. [Available online at http://www.bioone.org/doi/pdf/10.3394/0380-1330%282007%2933%5B566%3ADAFOEC%5D2.0.CO%3B2]

77. Sauer, E. P., J. L. VandeWalle, M. J. Bootsma, and S. L. McLellan, 2011: Detection of the human specific Bacteroides genetic marker provides evidence of widespread sewage contamination of stormwater in the urban environment. *Water Research*, **45,** 4081-4091, doi:10.1016/j.watres.2011.04.049. [Available online at http://v3.mmsd.com/AssetsClient/Documents/waterqualityresearch/Human_Specific_Bacteroides.pdf]

78. Mishra, V., K. A. Cherkauer, and S. Shukla, 2010: Assessment of drought due to historic climate variability and projected future climate change in the midwestern United States. *Journal of Hydrometeorology*, **11,** 46-68, doi:10.1175/2009JHM1156.1. [Available online at http://journals.ametsoc.org/doi/pdf/10.1175/2009JHM1156.1]

79. Reutter, J. M., J. Ciborowski, J. DePinto, D. Bade, D. Baker, T. B. Bridgeman, D. A. Culver, S. Davis, E. Dayton, D. Kane, R. W. Mullen, and C. M. Pennuto, 2011: Lake Erie Nutrient Loading and Harmful Algal Blooms: Research Findings and Management Implications. Final Report of the Lake Erie Millennium Network Synthesis Team, 17 pp., Ohio Sea Grant College Program, The Ohio State University, Lake Erie Millennium Network, Columbus, OH. [Available online at http://www.ohioseagrant.osu.edu/_documents/publications/TS/TS-060%20 20June2011LakeErieNutrientLoadingAndHABSfinal.pdf]

80. Dai, A., 2010: Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, **2,** 45-65, doi:10.1002/wcc.81.

81. Dobiesz, N. E., and N. P. Lester, 2009: Changes in mid-summer water temperature and clarity across the Great Lakes between 1968 and 2002. *Journal of Great Lakes Research*, **35,** 371-384, doi:10.1016/j.jglr.2009.05.002.

82. Lofgren, B., and A. Gronewold, 2012: Water Resources. *U.S. National Climate Assessment Midwest Technical Input Report*, J. Winkler, J. Andresen, J. Hatfield, D. Bidwell, and D. Brown, Eds., Great Lakes Integrated Sciences and Assessments (GLISA) Center. [Available online at http://glisa.msu.edu/docs/NCA/MTIT_WaterResources.pdf]

83. Austin, J. A., and S. M. Colman, 2007: Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: A positive ice-albedo feedback. *Geophysical Research Letters*, **34,** L06604, doi:10.1029/2006GL029021. [Available online at http://www.cee.mtu.edu/~reh/papers/pubs/non_Honrath/austin07_2006GL029021.pdf]

84. Mackey, S., 2012: Great Lakes nearshore and coastal systems. *U.S. National Climate Assessment Midwest Technical Input Report*, J. Winkler, J. Andresen, J. Hatfield, D. Bidwell, and D. Brown, Eds., Great Lakes Integrated Sciences and Assessments (GLISA), National Laboratory for Agriculture and the Environment, 14. [Available online at http://glisa.msu.edu/docs/NCA/MTIT_Coastal.pdf]

85. Trumpickas, J., B. J. Shuter, and C. K. Minns, 2009: Forecasting impacts of climate change on Great Lakes surface water temperatures. *Journal of Great Lakes Research*, **35,** 454-463, doi:10.1016/j.jglr.2009.04.005.

86. Ficke, A. D., C. A. Myrick, and L. J. Hansen, 2007: Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries*, **17,** 581-613, doi:10.1007/s11160-007-9059-5.

87. Bronte, C. R., M. P. Ebener, D. R. Schreiner, D. S. DeVault, M. M. Petzold, D. A. Jensen, C. Richards, and S. J. Lozano, 2003: Fish community change in Lake Superior, 1970–2000. *Canadian Journal of Fisheries and Aquatic Sciences*, **60,** 1552-1574, doi:10.1139/f03-136.

Rahel, F. J., B. Bierwagen, and Y. Taniguchi, 2008: Managing aquatic species of conservation concern in the face of climate change and invasive species. *Conservation Biology*, **22,** 551-561, doi:10.1111/j.1523-1739.2008.00953.x. [Available online at http://onlinelibrary.wiley.com/doi/10.1111/j.1523-1739.2008.00953.x/pdf]

88. Bai, X., and J. Wang, 2012: Atmospheric teleconnection patterns associated with severe and mild ice cover on the Great Lakes, 1963–2011. *Water Quality Research Journal of Canada* **47,** 421–435, doi:10.2166/wqrjc.2012.009.

89. Pryor, S. C., R. J. Barthelmie, D. T. Young, E. S. Takle, R. W. Arritt, D. Flory, W. J. Gutowski, Jr., A. Nunes, and J. Roads, 2009: Wind speed trends over the contiguous United States. *Journal of Geophysical Research*, **114,** 2169-8996, doi:10.1029/2008JD011416.

90. Ferris, G., cited 2012: State of the Great Lakes 2009. Climate change: Ice duration on the Great Lakes. Environment Canada and United States Environmental Protection Agency. [Available online at http://www.epa.gov/solec/sogl2009/]

Wuebbles, D. J., K. Hayhoe, and J. Parzen, 2010: Introduction: Assessing the effects of climate change on Chicago and the Great Lakes. *Journal of Great Lakes Research*, **36,** 1-6, doi:10.1016/j.jglr.2009.09.009.

91. Millerd, F., 2011: The potential impact of climate change on Great Lakes international shipping. *Climatic Change*, **104,** 629-652, doi:10.1007/s10584-010-9872-z.

92. Hellmann, J. J., J. E. Byers, B. G. Bierwagen, and J. S. Dukes, 2008: Five potential consequences of climate change for invasive species. *Conservation Biology*, **22,** 534-543, doi:10.1111/j.1523-1739.2008.00951.x. [Available online at http://onlinelibrary.wiley.com/doi/10.1111/j.1523-1739.2008.00951.x/pdf]

Smith, A. L., N. Hewitt, N. Klenk, D. R. Bazely, N. Yan, S. Wood, I. Henriques, J. I. MacLellan, and C. Lipsig-Mummé, 2012: Effects of climate change on the distribution of invasive alien species in Canada: A knowledge synthesis of range change projections in a warming world. *Environmental Reviews*, **20,** 1-16, doi:10.1139/a11-020.

93. Sousounis, P., and J. M. Bisanz, Eds., 2000: *Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change: Great Lakes.* University of Michigan, Atmospheric, Oceanic and Space Sciences Department, 116 pp. [Available online at http://www.gcrio.org/NationalAssessment/greatlakes/greatlakes.pdf]

94. IUGLSB, 2012: Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels. Final Report to the International Joint Commission. March 2012, 236 pp., International Upper Great Lakes Study Board, Ottawa, ON [Available online at http://www.ijc.org/iuglsreport/wp-content/report-pdfs/Lake_Superior_Regulation_Full_Report.pdf]

95. Angel, J. R., and K. E. Kunkel, 2010: The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron. *Journal of Great Lakes Research*, **36,** 51-58, doi:10.1016/j.jglr.2009.09.006.

96. Hayhoe, K., J. VanDorn, T. Croley, II, N. Schlegal, and D. Wuebbles, 2010: Regional climate change projections for Chicago and the US Great Lakes. *Journal of Great Lakes Research*, **36,** 7-21, doi:10.1016/j.jglr.2010.03.012. [Available online at http://www.bioone.org/doi/pdf/10.1016/j.jglr.2010.03.012]

97. MacKay, M., and F. Seglenieks, 2012: On the simulation of Laurentian Great Lakes water levels under projections of global climate change. *Climatic Change*, **117,** 55-67, doi:10.1007/s10584-012-0560-z.

Lofgren, B. M., T. S. Hunter, and J. Wilbarger, 2011: Effects of using air temperature as a proxy for potential evapotranspiration in climate change scenarios of Great Lakes basin hydrology. *Journal of Great Lakes Research*, **37,** 744-752, doi:10.1016/j.jglr.2011.09.006.

98. Winkler, J., J. Andresen, and J. Hatfield, Eds., 2012: *Midwest Technical Input Report: Prepared for the US National Climate Assessment.* 236 pp.

99. Zhang, F., J. M. Chen, Y. Pan, R. A. Birdsey, S. Shen, W. Ju, and L. He, 2012: Attributing carbon changes in conterminous US forests to disturbance and non-disturbance factors from 1901 to 2010. *Journal of Geophysical Research*, **117**, doi:10.1029/2011JG001930.

100. Pryor, S. C., Ed., 2013: *Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation.* Indiana University Press, 288 pp.

101. Wang, J., X. Bai, H. Hu, A. Clites, M. Colton, and B. Lofgren, 2012: Temporal and spatial variability of Great Lakes ice cover, 1973-2010. *Journal of Climate*, **25,** 1318-1329, doi:10.1175/2011JCLI4066.1.

102. Karl, T. R., J. T. Melillo, and T. C. Peterson, Eds., 2009: *Global Climate Change Impacts in the United States.* Cambridge University Press, 189 pp. [Available online at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf]

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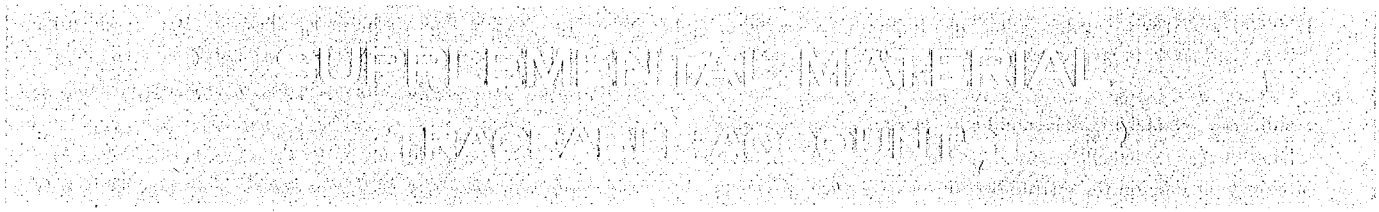


Process for Developing Key Messages:

The assessment process for the Midwest Region began with a workshop was that was held July 25, 2011, in Ann Arbor, Michigan. Ten participants discussed the scope and authors for a foundational Technical Input Report (TIR) report entitled "Midwest Technical Input Report."[98] The report, which consisted of nearly 240 pages of text organized into 13 chapters, was assembled by 23 authors representing governmental agencies, non-governmental organizations (NGOs), tribes, and other entities.

The Chapter Author Team engaged in multiple technical discussions via teleconferences that permitted a careful review of the foundational TIR[98] and of approximately 45 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. The Chapter Author Team convened teleconferences and exchanged extensive emails to define the scope of the chapter for their expert deliberation of input materials and to generate the chapter text and figures. Each expert drafted key messages, initial text and figure drafts and traceable accounts that pertained to their individual fields of expertise. These materials were then extensively discussed by the team and were approved by the team members.

Key message #1 Traceable Account

In the next few decades, longer growing seasons and rising carbon dioxide levels will increase yields of some crops, though those benefits will be progressively offset by extreme weather events. Though adaptation options can reduce some of the detrimental effects, in the long term, the combined stresses associated with climate change are expected to decrease agricultural productivity.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.[98] Technical input reports on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for altered growing seasons across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Message 4) and its Traceable Accounts. "Climate Trends and Scenarios for the U.S. National Climate Assessment"[4] and its references provide specific details for the Midwest. Evidence for longer growing seasons in the Midwest is based on regional temperature records and is incontrovertible, as is evidence for increasing carbon dioxide concentrations.

U.S. Department of Agriculture data tables provide evidence for the importance of the eight Midwest states for U.S. agricultural production.[8] Evidence for the effect of future elevated carbon dioxide concentrations on crop yields is based on scores of greenhouse and field experiments that show a strong fertilization response for C_3 plants such as soybeans and wheat and a positive but not as strong a response for C_4 plants such as corn. Observational data, evidence from field experiments, and quantitative modeling are the evidence base of the negative effects of extreme weather events on crop yield: early spring heat waves followed by normal frost events have been shown to decimate Midwest fruit crops; heat waves during flowering, pollination, and grain filling have been shown to significantly reduce corn and wheat yields; more variable and intense spring rainfall has delayed spring planting in some years and can be expected to increase erosion and runoff; and floods have led to crop losses.[12,13,14]

New information and remaining uncertainties

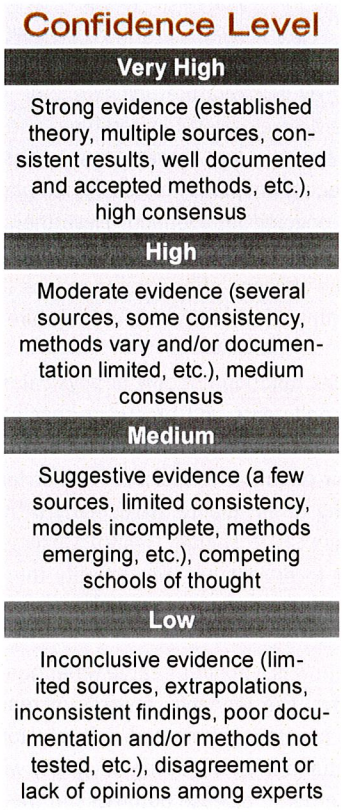
Key issues (uncertainties) are: a) the rate at which grain yield improvements will continue to occur, which could help to offset the overall negative effect of extreme events at least for grain crops (though not for individual farmers); and b) the degree to which genetic improvements could make some future crops more tolerant of extreme events such as drought and heat stress. Additional uncertainties are: c) the degree to which accelerated soil carbon loss will occur as a result of warmer winters and the resulting effects on soil fertility and soil water availability; and d) the potential for increased pest and disease pressure as southern pests such as soybean rust move northward and existing pests better survive milder Midwest winters.

Assessment of confidence based on evidence

Because nearly all studies published to date in the peer-reviewed literature agree that Midwest crops benefit from CO_2 fertilization and some benefit from a longer growing season, there is **very high** confidence in this component of the key message.

Studies also agree that full benefits of climate change will be offset partly or fully by more frequent heat waves, early spring thaws followed by freezing temperatures, more variable and intense rainfall events, and floods. Again, there is **very high** confidence in this aspect.

There is less certainty (**high**) about pest effects and about the potential for adaptation actions to significantly mitigate the risk of crop loss.



Key Message #2 Traceable Account

The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward. The role of the region's forests as a net absorber of carbon is at risk from disruptions to forest ecosystems, in part due to climate change.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.[98] Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for increased temperatures and altered growing seasons across the U.S. is discussed in Chapter 2 (Our Changing Climate, Key Messages 3 and 4) and its Traceable Accounts. "Climate Trends and Scenarios for the U.S. National Climate Assessment,"[4] with its references, provides specific details for the Midwest. Evidence that species have been shifting northward or ascending in altitude has been mounting for numerous species, though less so for long-lived trees. Nearly all studies to date published in the peer-reviewed literature agree that many of the boreal species of the north will eventually retreat northward. The question is when. Multiple models and paleoecological evidence show these trends have occurred in the past and are projected to continue in the future.[36]

The forests of the eastern United States (including the Midwest) have been accumulating large quantities of carbon over the past century,[23] but evidence shows this trend is slowing in recent decades. There is a large amount of forest inventory data supporting the gradual decline in carbon accumulation throughout the eastern United States,[99] as well as evidence of increasing disturbances and disturbance agents that are reducing overall net productivity in many of the forests.

New information and remaining uncertainties

A key issue (uncertainty) is the rate of change of habitats and for organisms adapting or moving as habitats move. The key questions are: How much will the habitats change (what scenarios and model predictions will be most correct)? As primary habitats move north, which species will be able to keep up with changing habitats on their own or with human intervention through assisted migration, management of migration corridors, or construction or maintenance of protected habitats within species' current landscapes?

Viable avenues to improving the information base are determining which climate models exhibit the best ability to reproduce the historical and potential future change in habitats, and determining how, how fast, and how far various species can move or adapt.

An additional key source of uncertainty is whether projected disturbances to forests are chronic or episodic in nature.[45]

Assessment of confidence based on evidence

There is **very high** confidence in this key message, given the evidence base and remaining uncertainties.

Key Message #3 Traceable Account

Increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality will increase public health risks.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.[98] Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for extreme weather such as heat waves across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Message 7) and its Traceable Accounts. Specific details for the Midwest are in "Climate Trends and Scenarios for the U.S. National Climate Assessment"[4] with its references. A recent book[100] also contains chapters detailing the most current evidence for the region.

Heat waves: The occurrence of heat waves in the recent past has been well-documented,[1,15,49] as have health outcomes (particularly with regards to mortality). Projections of thermal regimes indicate increased frequency of periods with high air temperatures (and high apparent temperatures, which are a function of both air temperature and humidity). These projections are relatively robust and consistent between studies.

Humidity: Evidence on observed and projected increased humidity can be found in a recent study.[49]

Air quality: In 2008, in the region containing North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio, over 26 million people lived in counties that failed the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ (particles with diameter below 2.5 microns), and over 24 million lived in counties that failed the NAAQS for ozone (O_3).[1] Because not all counties have air quality measurement stations in place, these data must be considered a lower bound on the actual number of counties that violate the NAAQS. Given that the NAAQS were designed principally with the goal of protecting human health, failure to meet these standards implies a significant fraction of the population live in counties characterized by air quality that is harmful to human health. While only relatively few studies have sought to make detailed air quality projections for the future, those that have[1] generally indicate declining air quality (see uncertainties below).

Water quality: The EPA estimates there are more than 800 billion gallons of untreated combined sewage released into the nation's waters annually.[76] Combined sewers are designed to capture both sanitary sewage and stormwater. Combined sewer overflows lead to discharge of untreated sewage as a result of precipitation events, and can threaten human health. While not all urban areas within the Midwest have combined sewers for delivery to wastewater treatment plants, many do (for example, Chicago and Milwaukee), and such systems are vulnerable to combined sewer overflows during extreme precipitation events. Given projected increases in the frequency and intensity of extreme precipitation events in the Midwest (Chapter 2: Our Changing Climate, Key Message 6),[75] it appears that sewer overflow will continue to constitute a significant current health threat and a critical source of climate change vulnerability for major urban areas within the Midwest.

New information and remaining uncertainties

Key issues (uncertainties) are: Human health outcomes are contingent on a large number of non-climate variables. For example, morbidity and mortality outcomes of extreme heat are strongly determined by a) housing stock and access to air-conditioning in residences; b) existence and efficacy of heat wave warning and response plans (for example, foreign-language-appropriate communications and transit plans to public cooling centers, especially for the elderly); and c) co-stressors (for example, air pollution). Further, heat stress is dictated by apparent temperature, which is a function of both air temperature and humidity. Urban heat islands tend to exacerbate elevated temperatures and are largely determined by urban land use and human-caused heat emissions. Urban heat island reduction plans (for example, planted green roofs) represent one ongoing intervention. Nevertheless, the occurrence of extreme heat indices will increase under all climate scenarios. Thus, in the absence of policies to reduce heat-related illness/death, these impacts will increase in the future.

Air quality is a complex function not only of physical meteorology but emissions of air pollutants and precursor species. However, since most chemical reactions are enhanced by warmer temperatures, as are many air pollutant emissions, warmer temperatures may lead to worsening of air quality, particularly with respect to tropospheric ozone (see Ch. 9: Human Health). Changes in humidity are more difficult to project but may amplify the increase in heat stress due to rising temperatures alone.[49]

Combined sewer overflow is a major threat to water quality in some midwestern cities now. The tendency towards increased magnitude of extreme rain events (documented in the historical record and projected to continue in downscaling analyses) will cause an increased risk of waterborne disease outbreaks in the absence of infrastructure overhaul. However, mitigation actions are available, and the changing structure of cities (for example, reducing impervious surfaces) may offset the impact of the changing climate.

Assessment of confidence based on evidence

In the absence of concerted efforts to reduce the threats posed by heat waves, increased humidity, degraded air quality and degraded water quality, climate change will increase the health risks associated with these phenomena. However, these projections are contingent on underlying assumptions regarding socioeconomic conditions and demographic trends in the region. Confidence is therefore **high** regarding this key message.

Key Message #4 Traceable Account

The Midwest has a highly energy-intensive economy with per capita emissions of greenhouse gases more than 20% higher than the national average. The region also has a large and increasingly utilized potential to reduce emissions that cause climate change.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.[98] Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

The Midwest's disproportionately large reliance on coal for electricity generation and the energy intensity of its agricultural and manufacturing sectors are all well documented in both government and industry records, as is the Midwest's contribution to greenhouse gases.[1] The region's potential for zero- and lower-carbon energy production is also well documented by government and private assessments. Official and regular reporting by state agencies and non-governmental organizations demonstrates the Midwest's progress toward a decarbonized energy mix (Ch. 4: Energy; Ch. 10: Energy, Water, and Land).[1]

There is evidence that the Midwest is steadily decarbonizing its electricity generation through a combination of new state-level policies (for example, energy efficiency and renewable energy standards) and will continue to do so in response to low natural gas prices, falling prices for renewable electricity (for example, wind and solar), greater market demand for lower-carbon energy from consumers, and new EPA regulations governing new power plants. Several midwestern states have established Renewable Portfolio Standards (see https://www.misoenergy.org/WhatWeDo/StrategicInitiatives/Pages/RenewablePortfolioStandards.aspx).

New information and remaining uncertainties

There are four key uncertainties. The first uncertainty is the net effect of emerging EPA regulations on the future energy mix of the Midwest. Assessments to date suggest a significant number of coal plants will be closed or repowered with lower-carbon natural gas; and even coal plants that are currently thought of as "must run" (to maintain the electric grid's reliability) may be able to be replaced in some circumstances with the right combination of energy efficiency, new transmission lines, demand response, and distributed generation. A second key uncertainty is whether or not natural gas prices will remain at their historically low levels. Given that there are really only five options for meeting electricity demand – energy efficiency, renewables, coal, nuclear, and natural gas – the replacement of coal with natural gas for electricity production would have a significant impact on greenhouse gas emissions in the region. Third is the uncertain future for federal policies that have spurred renewable energy development to date, such as the Production Tax Credit for wind. While prices for both wind and solar continue to fall, the potential loss of tax credits may dampen additional market penetration of these technologies. A fourth uncertainty is the net effect of climate change on energy demand, and the cost of meeting that new demand profile. Research to date suggests the potential for a significant swing from the historically larger demand for heating in the winter to more demand in the summer instead, due to a warmer, more humid climate.[3]

Assessment of confidence based on evidence

There is no dispute about the energy intensity of the midwestern economy, nor its disproportionately large contribution of greenhouse gas emissions. Similarly, there is broad agreement about the Midwest's potential for—and progress toward—lower-carbon electricity production. There is therefore **very high** confidence in this statement.

Key Message #5 Traceable Account

Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.[98] Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for extreme weather and increased precipitation across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Messages 5, 6, and 7) and its Traceable Accounts. Specific details for the Midwest are detailed in "Climate Trends and Scenarios for the U.S. National Climate Assessment"[4] with its references. A recent book[100] also contains chapters detailing the most current evidence for the region.

There is compelling evidence that annual total precipitation has been increasing in the region, with wetter winters and springs, drier summers, an increase in extreme precipitation events, and changes in snowfall patterns. These observations are consistent with climate model projections. Both the observed trends and climate models suggest these trends will increase in the future.

Recent records also indicate evidence of a number of high-impact flood events in the region. Heavy precipitation events cause increased kinetic energy of surface water and thus increase erosion. Heavy precipitation events in the historical records have been shown to be associated with discharge of partially or completely untreated sewage due to the volumes of water overwhelming combined sewer systems that are designed to capture both domestic sewage and stormwater.

Climate downscaling projections tend to indicate an increase in the frequency and duration of extreme events (both heavy precipitation and meteorological drought) in the future.

An extensive literature survey and synthetic analysis is presented in chapters in a recent book[100] for impacts on water quality, transportation, agriculture, health, and infrastructure.

New information and remaining uncertainties

Precipitation is much less readily measured or modeled than air temperature.[3] Thus both historical tendencies and projections for precipitation are inherently less certain than for temperature. Most regional climate models still have a positive bias in precipitation frequency but a negative bias in terms of precipitation amount in extreme events.

Flood records are very heterogeneous and there is some ambiguity about the degree to which flooding is a result of atmospheric conditions.[69] Flooding is not solely the result of incident precipitation but is also a complex function of the preceding conditions such as soil moisture content and extent of landscape infiltration. A key issue (uncertainty) is the future distribution of snowfall. Records indicate that snowfall is decreasing in the southern parts of the region, along with increasing lake effect snow. Climate models predict these trends will increase. There is insufficient knowledge about how this change in snowfall patterns will affect flooding and associated problems, but it is projected to affect the very large spring floods that typically cause the worst flooding in the region. In addition, recent data and climate predictions indicate drier summer conditions, which could tend to offset the effects of higher intensity summer storms by providing increased water storage in the soils. The relative effects of these offsetting trends need to be assessed. To determine future flooding risks, hydrologic modeling is needed that includes the effects of the increase in extreme events, changing snow patterns, and shifts in rainfall patterns. Adaptation measures to reduce soil erosion and combined sewer overflow (CSO) events are available and could be widely adopted.

The impacts of increased magnitude of heavy precipitation events on water quality, agriculture, human health, transportation, and infrastructure will be strongly determined by the degree to which the resilience of such systems is enhanced (for example, some cities are already implementing enhanced water removal systems).

Assessment of confidence based on evidence

There have been improvements in agreement between observed precipitation patterns and model simulations. Also an increase in extreme precipitation events is consistent with first-order reasoning and increased atmospheric water burdens due to increased air temperature. Recent data suggest an increase in flooding in the region but there is uncertainty about how changing snow patterns will affect flood events in the future. Thus there is **high** confidence in increases in high-magnitude rainfall events and extreme precipitation events, and that these trends are expected to continue. There is **medium** confidence that, in the absence of substantial adaptation actions, the enhancement in extreme precipitation and other tendencies in land use and land cover result in a projected increase in flooding. There is **medium** confidence that, in the absence of major adaptation actions, the enhancement in extreme precipitation will tend to increase the risk of erosion, declines in water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.[3]

Key Message #6 Traceable Account

Climate change will exacerbate a range of risks to the Great Lakes, including changes in the range and distribution of certain fish species, increased invasive species and harmful blooms of algae, and declining beach health. Ice cover declines will lengthen the commercial navigation season.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.[98] Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for changes in ice cover due to increased temperatures across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Message 11) and its Traceable Accounts. Specific details for the Midwest are detailed in "Climate Trends and Scenarios for the U.S. National Climate Assessment"[4] with its references. A recent book[100] also contains chapters detailing the most current evidence for the region.

Altered fish communities: Warmer lakes and streams will certainly provide more habitat for warmwater species as conditions in northern reaches of the basin become more suitable for warmwater fish and as lakes and streams are vacated by cool- and coldwater species.[84] Habitat for coldwater fish, though not expected to disappear, will shrink substantially, though it could also expand in some areas, such as Lake Superior. Whether climate change expands the range of any type of fish is dependent on the availability of forage fish, as higher temperatures also necessitate greater food intake.

Increased abundances of invasive species: As climate change alters water temperatures, habitat, and fish communities, conditions that once were barriers to alien species become conduits for establishment and spread.[84] This migration will alter drastically the fish communities of the Great Lakes basin. Climate change is also projected to heighten the impact of invasive species already present in the Great Lakes basin. Warmer winter conditions, for instance, have the potential to benefit alewife, round gobies, ruffe, sea lamprey, rainbow smelt, and other non-native species. These species have spread rapidly throughout the basin and have already inflicted significant ecological and economic harm.

Declining beach health and harmful algal blooms: Extreme events increase runoff, adding sediments, pollutants, and nutrients to the Great Lakes. The Midwest has experienced rising trends in precipitation and runoff. Agricultural runoff, in combination with increased water temperatures, has caused considerable non-point source pollution problems in recent years, with increased phosphorus and nitrogen loadings from farms contributing to more frequent and prolonged occurrences of anoxic "dead zones" and harmful, dense algae growth for long periods. Stormwater runoff that overloads urban sewer systems during extreme events adds to increased levels of toxic substances, sewage, and bacteria in the Great Lakes, affecting water quality, beach health, and human well-being. Increased storm events caused by climate change will lead to an increase in combined sewer overflows.[84]

Decreased ice cover: Increasingly mild winters have shortened the time between when a lake freezes and when it thaws.[101] Scientists have documented a relatively constant decrease in Great Lakes ice cover since the 1970s, particularly for Lakes Superior, Michigan, Huron, and Ontario. The loss of ice cover on the Great Lakes has both ecological and economic implications. Ice serves to protect shorelines and habitat from storms and wave power. Less ice—coupled with more frequent and intense storms—leaves shores vulnerable to erosion and flooding and could harm property and fish habitat.

Water levels: The 2009 NCA[102] included predictions of a significant drop in Great Lakes levels by the end of the century, based on methods of linking climate models to hydrologic models. These methods have been significantly improved by fully coupling the hydrologic cycle among land, lake, and atmosphere.[97] Without accounting for that cycle of interactions, a study[96] concluded that increases in precipitation would be negated by increases in winter evaporation from less ice cover and by increases in summer evaporation and evapotranspiration from warmer air temperatures, under a scenario of continued increases in global emissions (SRES A2 scenario). Declines of 8 inches to 2 feet have been projected by the end of this century, depending on the specific lake in question.[96] A recent comprehensive assessment,[94] however, has concluded that with a continuation of current rising emissions trends (A2), the lakes will experience a slight decrease or even a rise in water levels; the difference from earlier studies is because earlier studies tended to overstress the amount of evapotranspiration expected to occur. The range of potential future lake levels remains large and includes the earlier projected decline. Overall, however, scientists project an increase in precipitation in the Great Lakes region (with extreme events projected to contribute to this increase), which will contribute to maintenance of or an increase in Great Lakes water levels. However, water level changes are not predicted to be uniform throughout the basin.

Shipping: Ice cover is expected to decrease dramatically by the end of the century, possibly lengthening the shipping season and, thus, facilitating more shipping activity. Current science suggests water levels in the Great Lakes are projected to fall slightly or might even rise over the short run. However, by causing even a small drop in water levels, climate change could make the costs of shipping increase substantially. For instance, for every inch of draft a 1000-foot ship gives up, its capacity is reduced by 270 tons.[93] Lightened loads today already add about $200,000 in costs to each voyage.

New information and remaining uncertainties

Key issues (uncertainties) are: Water levels are influenced by the amount of evaporation from decreased ice cover and warmer air temperatures, by evapotranspiration from warmer air temperatures, and by potential increases in inflow from more precipitation. Uncertainties about Great Lakes water levels are high, though most models suggest that the decrease in ice cover will lead to slightly lower water levels, beyond natural fluctuations.

The spread of invasive species into the system is near-certain (given the rate of introductions over the previous 50 years) without major policy and regulatory changes. However, the changes in Great Lakes fish communities are based on extrapolation from known fishery responses to projected responses to expected changing conditions in the basin. Moreover, many variables beyond water temperature and condition affect fisheries, not the least of which is the availability of forage fish. Higher water temperatures necessitate greater food intake, yet the forage base is changing rapidly in many parts of the Great Lakes basin, thus making the projected impact of climate change on fisheries difficult to discern with very high certainty.

Assessment of confidence based on evidence

Peer-reviewed literature about the effects of climate change are in broad agreement that air and surface water temperatures are rising and will continue to do so, that ice cover is declining steadily, and that precipitation and extreme events are on the rise. For large lake ecosystems, these changes have well-documented effects, such as effects on algal production, stratification (change in water temperature with depth), beach health, and fisheries. Key uncertainties exist about Great Lakes water levels and the impact of climate change on fisheries.

A qualitative summary of climate stressors and coastal margin vulnerabilities for the Great Lakes is given in a technical input report.[84] We have high confidence that the sum of these stressors will exceed the risk posed by any individual stressor. However, quantifying the cumulative impacts of those stressors is very challenging.

Given the evidence and remaining uncertainties, there is **very high** confidence in this key message, except **high** confidence for lake levels changing, and **high** confidence that declines in ice cover will continue to lengthen the commercial navigation season. There is limited information regarding exactly how invasive species may respond to changes in the regional climate, resulting in **medium** confidence for that part of the key message.

Great Lakes Water Quality Agreement Annex 1

Areas of Concern

A. Purpose

The purpose of this Annex is to contribute to the achievement of the General and Specific Objectives of this Agreement by restoring beneficial uses that have become impaired due to local conditions at Areas of Concern (AOCs), through the development and implementation of Remedial Action Plans (RAPs) for each AOC designated pursuant to this Agreement.

B. Programs and Other Measures

An AOC is a geographic area designated by the Parties where significant impairment of beneficial uses has occurred as a result of human activities at the local level.

The Parties have designated AOCs and may, after consulting with State and Provincial Governments, Tribal Governments, First Nations, Métis, Municipal Governments, watershed management agencies, other local public agencies, the Public, and the Commission as appropriate, designate additional AOCs based on an evaluation of Beneficial Use Impairments (BUIs). A BUI is a reduction in the chemical, physical or biological integrity of the Waters of the Great Lakes sufficient to cause any of the following:

1. **restrictions on fish and wildlife consumption**;
2. tainting of fish and wildlife flavour;
3. **degradation of fish and wildlife populations**;
4. **fish tumours or other deformities**;
5. bird or animal deformities or reproduction problems;
6. **degradation of benthos**;
7. **restrictions on dredging activities**;
8. eutrophication or undesirable algae;
9. restrictions on drinking water consumption, or taste and odour problems;
10. **beach closings**;
11. **degradation of aesthetics**;
12. added costs to agriculture or industry;
13. degradation of phytoplankton and zooplankton populations; and
14. **loss of fish and wildlife habitat**.

For each AOC, the Parties, in cooperation and consultation with State and Provincial Governments, Tribal Governments, First Nations, Métis, Municipal Governments, watershed management agencies, other local public agencies, and the Public, shall develop and implement a systematic and comprehensive ecosystem approach to restoring beneficial use.

The Parties shall cooperate with State and Provincial Governments to ensure that RAPs are developed, periodically updated, and implemented for each AOC. Each plan shall include:

1. identification of BUIs and causes;

2. criteria for the restoration of beneficial uses that take into account local conditions and established in consultation with the local community;

3. remedial measures to be taken, including identification of entities responsible for implementing these measures;

4. a summary of the implementation of remedial measures taken and the status of the beneficial use; and

5. a description of surveillance and monitoring processes to track the effectiveness of remedial measures and confirm restoration of beneficial uses.

A Party shall make RAPs and updated RAPs available to the Commission and the Public.

A Party shall remove a BUI designation when the established criteria have been met.

A Party may elect to identify an AOC as an AOC in Recovery when all remedial actions identified in the RAP have been implemented and monitoring confirms that recovery is progressing in accordance with the RAP. A Party shall monitor and take further action, if required, to restore beneficial uses within an AOC in Recovery.

A Party shall remove the designation of an AOC or AOC in Recovery when environmental monitoring confirms that beneficial uses have been restored in accordance with the criteria established in the RAP.

A Party shall solicit a review and comments from the State and Provincial Governments, Tribal Governments, First Nations, Métis, Municipal Governments, watershed management agencies, other local public agencies, the Public, and the Commission:

1. prior to the designation of an AOC in Recovery; and

2. prior to the removal of a designation as an AOC or an AOC in Recovery.

C. Reporting

The Parties shall report on progress toward implementation of this Annex every three years through the Progress Report of the Parties, including:

1. a listing of current AOCs;

2. the status of BUIs in each AOC;

3. the actions completed or initiated in each AOC during the reporting period; and

4. the remaining actions required in each AOC for the removal of the designation as an AOC.

St. Louis River Area of Concern
Remedial Action Plan Update

A Roadmap to Delisting

July 15, 2013

The St. Louis River Area of Concern (AOC) was listed as one of 43 AOCs on the Great Lakes in 1987. Historical actions such as improper municipal and industrial waste disposal and unchecked land use practices, including dredging and filling of aquatic habitat and damaging logging practices, contributed to the complex set of issues facing the AOC at the time it was listed. In 1992, the Remedial Action Plan determined that nine Beneficial Use Impairments (BUI) existed in the AOC.

The AOC Delisting Roadmap is a comprehensive plan that details the actions necessary to remove each of the BUIs identified for the St. Louis River AOC.

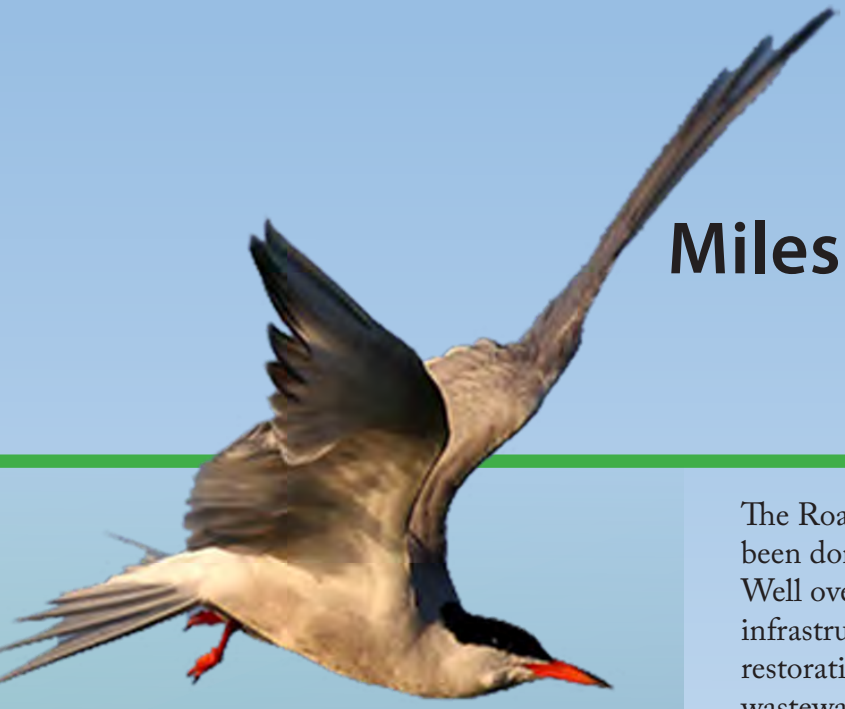
Development of the Roadmap was made possible through a Great Lakes Restoration initiative grant from the U.S. Environmental Protection Agency (U.S. EPA). Capacity funding from U.S. EPA allowed multiple organizations to work together in a concerted effort to complete the Roadmap. This effort supports the goal of removing the nine BUIs and delisting the AOC by 2025.

Geographic Focus

The St. Louis River AOC is large and complex, involving two states and tribal lands. It includes the lower 39 miles of the St. Louis River, from upstream of Cloquet, Minnesota, to the Duluth-Superior Harbor and Lake Superior, plus the Nemadji River watershed.

Photo by Dave Witt, Aero-Environmental Consulting; courtesy Duluth Seaway Port Authority

Miles Traveled Already – Progress to Date



Common Tern

Beneficial Use Impairments in the St. Louis River AOC

BUI 1: Fish Consumption Advisories
BUI 2: Degraded Fish and Wildlife Populations
BUI 3: Fish Tumors and Other Deformities
BUI 4: Degradation of Benthos
BUI 5: Restrictions on Dredging
BUI 6: Excessive Loading of Sediment and Nutrients
BUI 7: Beach Closings and Body Contact Restrictions
BUI 8: Degradation of Aesthetics
BUI 9: Loss of Fish and Wildlife Habitat

The sturgeon population in the St. Louis River was extirpated in the mid-20th century. Sturgeon fry were found in the St. Louis River in 2011 and 2013 – the first ever evidence of successful spawning since the sturgeon rehabilitation program began.

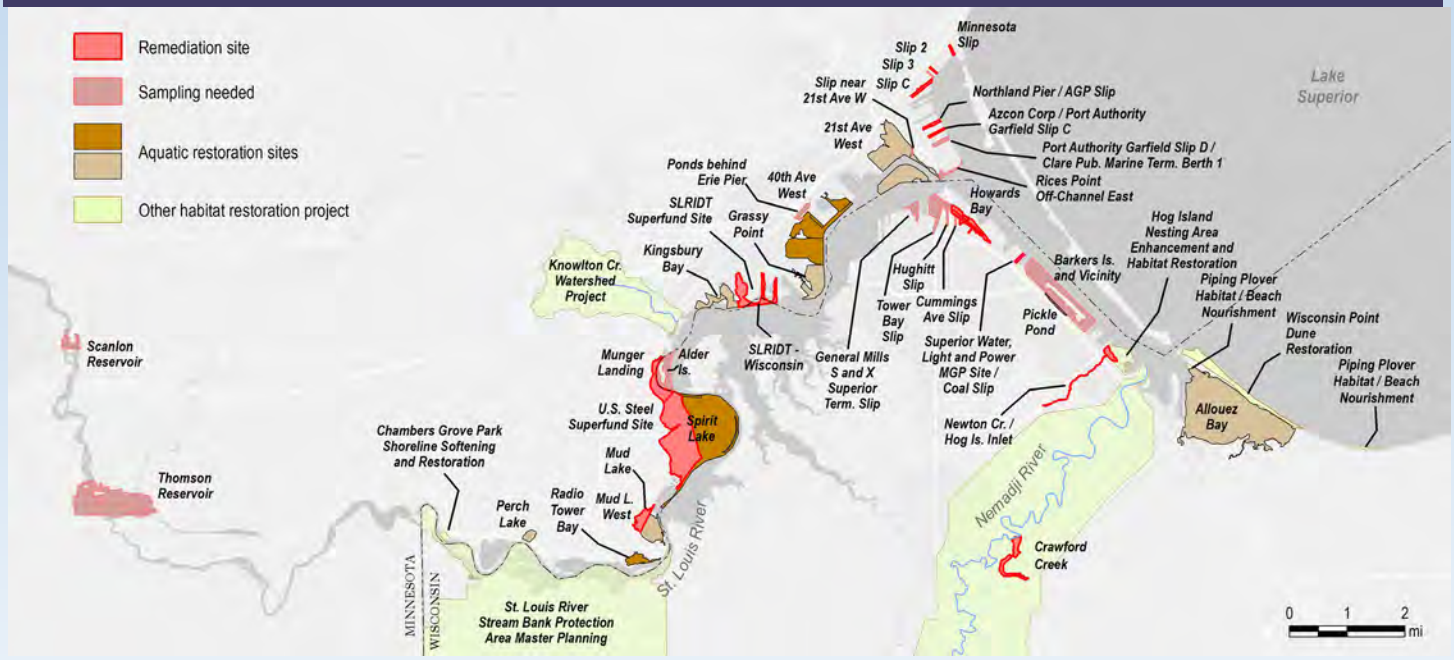
Photo by Brian Borkholder, FDL

The Roadmap begins after significant work has been done to restore the AOC since it was listed. Well over $420M has been invested since 1978 on infrastructure upgrades, remediation, and habitat restoration and protection. Improved municipal wastewater treatment and significant progress on control of wet weather overflows have contributed to water quality improvement and returning fish and wildlife populations. Some contaminated sites have been remediated and restored, including Hog Island Newtown Creek in Wisconsin and the St. Louis River Interlake Duluth Tar Superfund site in Minnesota. In addition, numerous habitat protection and restoration projects have been completed across the AOC. A few examples include:

- Protection of Clough Island
- Restoration of Tallas Island at the mouth of Knowlton Creek
- Protection of 6,500 acres of geologically sensitive habitat in the St. Louis River Stream Bank Protection Area
- Creation of colonial waterbird habitat creation at Wisconsin Point
- Protection of more than 4,500 acres in two Wisconsin State Natural Areas within the Pokegama River watershed

The Roadmap is the next step to build on this progress to address legacy sediment contamination and lost wetland habitat of the St. Louis River estuary.

Remediation and Restoration Sites in the St. Louis River AOC



The Roadmap is

- **Inclusive:** Developed by an extensive stakeholder involvement process led by Minnesota and Wisconsin with active participation of the Fond du Lac Band.
- **Strategic:** Provides strategies and actions to achieve removal objectives, and establishes a timeline and estimated costs to achieve objectives.
- **Targeted:** Sets an overall goal to delist the AOC by 2025 using funding sources, which include the federal Great Lakes Restoration Initiative (GLRI) and Minnesota's Clean Water, Land and Legacy.

Photo by Diane Desotelle, MPCA

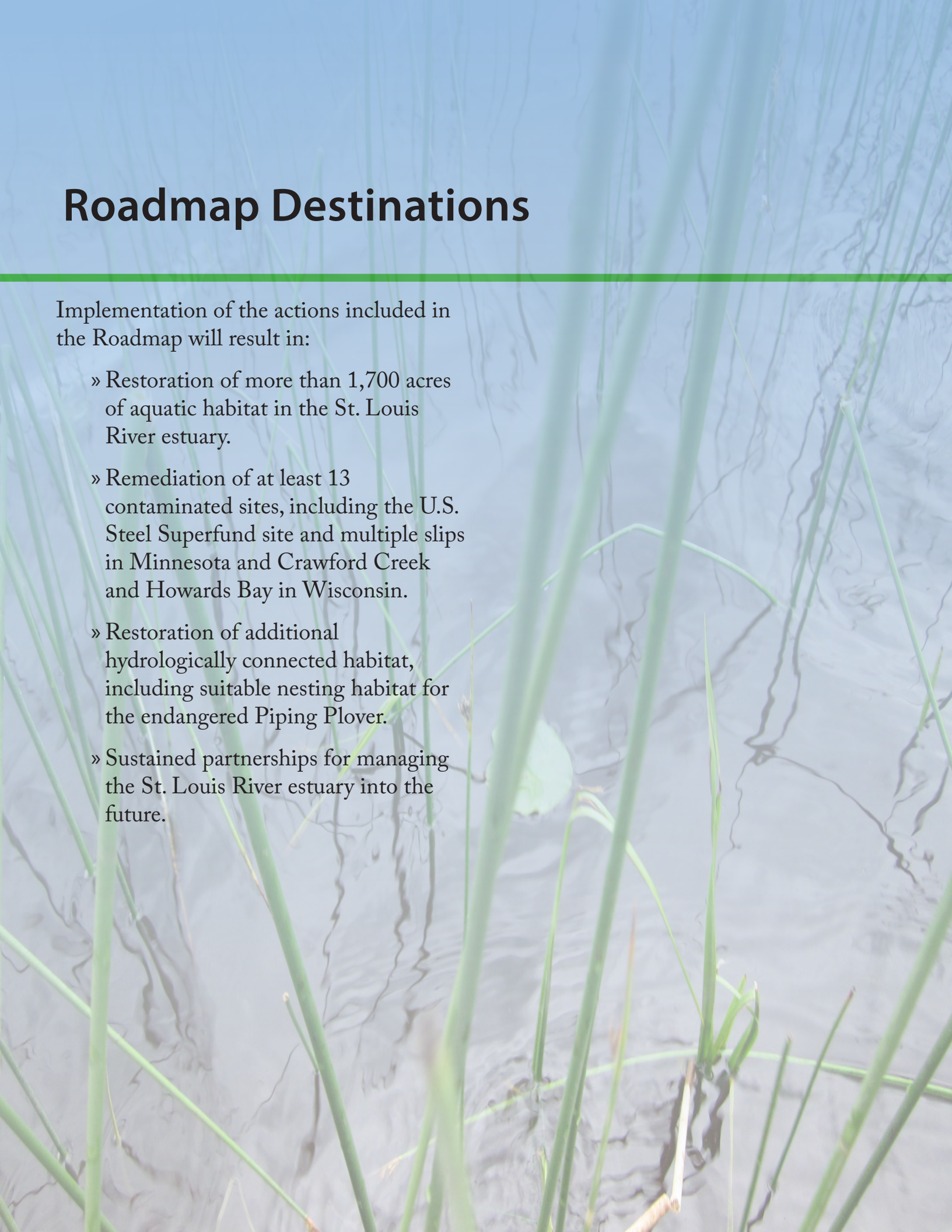
Anticipated BUI Removal Timeline

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
		BUI 8	BUI 2 BUI 3 BUI 6		BUI 7				BUI 4	BUI 5		BUI 1 BUI 9

Roadmap Destinations

Implementation of the actions included in the Roadmap will result in:

- Restoration of more than 1,700 acres of aquatic habitat in the St. Louis River estuary.
- Remediation of at least 13 contaminated sites, including the U.S. Steel Superfund site and multiple slips in Minnesota and Crawford Creek and Howards Bay in Wisconsin.
- Restoration of additional hydrologically connected habitat, including suitable nesting habitat for the endangered Piping Plover.
- Sustained partnerships for managing the St. Louis River estuary into the future.



The Roadmap gets us there

The Roadmap defines a path forward to restore and delist the AOC, so the legacy of the St. Louis River estuary can be redefined for generations of local residents and visitors.

Implementing the actions in the Roadmap will require an investment currently estimated ranging from $300-$400 million. It is critical that this needed investment be stable and sustained until the Roadmap is successfully completed and the AOC is delisted. In addition, the completion of this aggressive effort will require the continued involvement from multiple agencies, partners and citizens.

Leading and coordinating the Roadmap are representatives from:

Minnesota Pollution Control Agency (MPCA)

Wisconsin Department of Natural Resources (WDNR)

Minnesota Department of Natural Resources (MDNR)

Fond du Lac Band of Lake Superior Chippewa (FDL)

St. Louis River Alliance (SLRA)

For more information contact:

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Photo by Joel Flick, USFWS

Find the St. Louis River AOC RAP Roadmap at these web addresses:

MPCA - http://www.pca.state.mn.us/water/stlouisriveraoc

WDNR - http://dnr.wi.gov/topic/greatlakes/st.louis.html

U.S. EPA - http://www.epa.gov/greatlakes/aoc/stlouis/index.html

Minnesota Pollution Control Agency

WISCONSIN DEPT. OF NATURAL RESOURCES

Minnesota DEPARTMENT OF NATURAL RESOURCES

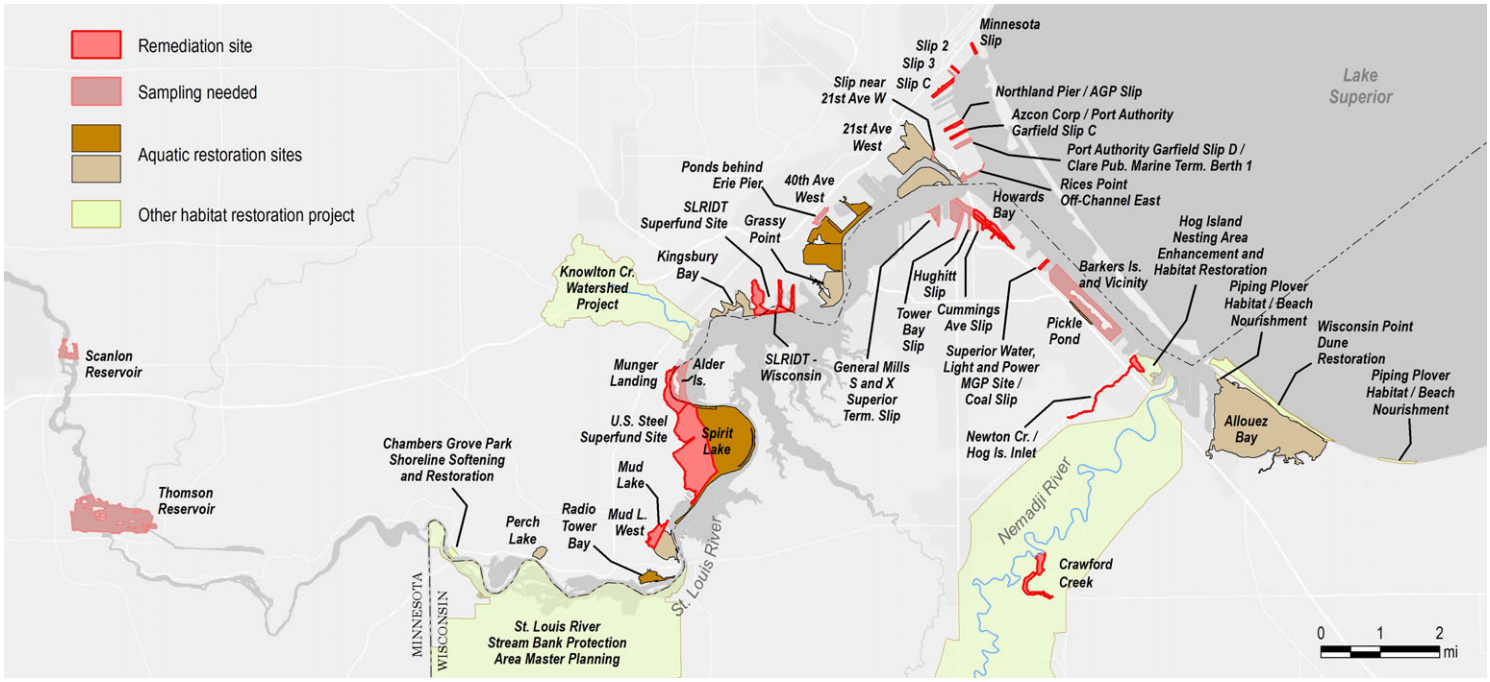
NAH-GAH-CHI-WA-NONG FOND DU LAC RESERVATION

PROTECT, RESTORE AND ENHANCE ST. LOUIS RIVER ALLIANCE

Great Lakes RESTORATION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT


Remediation site
Sampling needed
Aquatic restoration sites
Other habitat restoration project
Minnesota Slip
Slip 2
Slip 3
Slip C
Slip near 21st Ave W
21st Ave West
Northland Pier / AGP Slip
Azcon Corp / Port Authority Garfield Slip C
Port Authority Garfield Slip D / Clare Pub. Marine Term. Berth 1
Rices Point Off-Channel East
Howards Bay
Lake Superior
Ponds behind Erie Pier
40th Ave West
SLRIDT Superfund Site
Grassy Point
Kingsbury Bay
Knowlton Cr. Watershed Project
Hughitt Slip
Tower Bay Slip
Cummings Ave Slip
Barkers Is. and Vicinity
Hog Island Nesting Area Enhancement and Habitat Restoration
Piping Plover Habitat / Beach Nourishment
Wisconsin Point Dune Restoration
Pickle Pond
Scanlon Reservoir
Munger Landing
Alder Is.
SLRIDT - Wisconsin
General Mills S and X Superior Term. Slip
Superior Water, Light and Power MGP Site / Coal Slip
Newton Cr. / Hog Is. Inlet
Allouez Bay
U.S. Steel Superfund Site
Spirit Lake
Chambers Grove Park Shoreline Softening and Restoration
Mud Lake
Mud L. West
Radio Tower Bay
Perch Lake
Thomson Reservoir
St. Louis River
Nemadji River
Crawford Creek
MINNESOTA
WISCONSIN
St. Louis River Stream Bank Protection Area Master Planning
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Duluth News Tribune.com

John Linc Stine and Tom Landwehr, Published August 11 2013

Commissioners' view: St. Louis River is a gem worth saving

Steve Lindstrom / For the News Tribune

There never has been a more perfect time for restoring a place dear to Northlanders — the St. Louis River — from more than 130 years of accumulated environmental injury. For the first time, functional partnerships, dedicated funding and the will to achieve ambitious and realistic cleanup and restoration goals are perfectly aligned to help comprehensively restore the health of not only the headwaters of Lake Superior but the entire Great Lakes region.

As the News Tribune Opinion page recently noted, the Great Lakes are an invaluable environmental and economic resource (Our View: “Don’t cut funding for Great Lakes,” July 31) — and it all begins here in the Twin Ports. Lake Superior and the St. Louis River estuary provide vital environmental and economic benefits: abundant fresh water for communities, industries and wildlife and an environmentally efficient transportation system for raw materials and finished goods.

Less than two weeks ago, a diverse group of more than 100 local, state and federal agencies and community stakeholders announced a bold and aggressive 12-year plan to finish up the important work of removing the remaining contamination and restoring critical habitat by 2025 that will cost $300 million to $400 million. The plan represents the largest cleanup and restoration effort proposed in the Great Lakes, and we believe this is the perfect time to make this reasonable investment in the resources that sustain our economy and our environment.

The most recent infusion of Minnesota Clean Water Land and Legacy Amendment money leveraged matching federal Great Lakes Restoration Initiative money and will result in a $16 million kick-start for the immediate implementation of the plan’s priority actions. This unique state-federal funding partnership, along with resources from entities responsible for the pollution, will contribute greatly to the overall success of this effort over the next 12 years. Among the specific achievable and

measureable goals are the restoration of 1,700 acres of fish and wildlife habitat and the clean up of all identified sites with contaminated sediments that pose a risk to human health and the environment.

This effort is designed to simultaneously address local economic issues and environmental concerns.

Economically, Duluth-Superior is the largest port on the Great Lakes and supports 11,510 jobs, nearly $546 million in wages and an estimated $1.5 billion in business revenue.

Clearly, we all share a vested interest in our St. Louis River resource. Environmentally, the historic industrial and municipal development, before environmental awareness and regulation, resulted in "legacy impairments." Remnants of these once-sanctioned activities — including improper municipal and industrial waste disposal, unchecked land-use practices, dredging and filling of aquatic habitat and damaging logging practices — contributed to a complex set of pollution issues and natural resource losses that still exist today.

The local community began assessing and addressing these accumulated legacy impairment issues in the late 1980s. These activities led to the International Joint Commission designating the St. Louis River as an Area of Concern in 1987. It is one of 43 such designated sites throughout the Great Lakes. As a result, nine specific legacy impairments were identified and must be removed to declare the area fully restored. Importantly, even with this legacy of impairments, the St. Louis River remains an ecosystem of national significance that warrants further investment to ensure its ongoing viability.

We're building on nearly 30 years and $500 million spent thus far to address these impairments. The results to date are impressive. Improved municipal wastewater treatment and significant progress controlling storm- and waste-water overflows to Lake Superior have contributed to water-quality improvements and rebounding fish and wildlife populations. A huge step forward has been the restoration of spawning habitat for lake sturgeon followed by the successful natural reproduction of this important fish. There also has been progress on cleaning up and restoring industrially contaminated sites such as Hog Island/Newton Creek in Wisconsin and the St. Louis River Interlake/Duluth Tar and U.S. Steel Superfund sites in Minnesota.

Despite these significant achievements, we realize there is more work to be done — much more. The recently released plan identifies in great detail the bold actions that must be taken to complete this important effort. We now have the strategic partnerships in place and the community consensus to really implement the plan.

Why is this large project achievable? A big share of credit goes to Minnesota voters who had the foresight to approve the Clean Water Land and Legacy Amendment in 2008. This dedicated, reliable funding source puts the St. Louis River at a distinct advantage over other Great Lakes restoration efforts. Minnesota voters should be proud of their vote for clean-water protection.

The financial resources are within reach and, under Gov. Mark Dayton's leadership, we are committed to seeing it through.

John Linc Stine is commissioner of the Minnesota Pollution Control Agency. Tom Landwehr is commissioner of the Minnesota Department of Natural Resources. They wrote this exclusively for the News Tribune.