

starting a public discussion\*



# CLIMATE CHANGE

in the Great Lakes Region

**SUMMARY REPORT BY STEPHEN WITTMAN**

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**\*This report presents a summary of the “Starting a Public Discussion” series of eight seminars on climate change and some of its likely effects on Wisconsin and the Great Lakes region that were held at seven locations around the state in 2007.**

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**Three members of the Nobel Prize-winning Intergovernmental Panel on Climate Change were among the speakers for the series, which was sponsored by the University of Wisconsin Sea Grant Institute and the Wisconsin Coastal Management Program with funding from the National Oceanic & Atmospheric Administration.**

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# WHY CARE ABOUT CLIMATE CHANGE

“Everybody talks about the weather, but nobody does anything about it.” —*Mark Twain, 1897*

Climate regulates life on Earth. It determines how we live. It plays a deciding role in where we can live and how we survive or, in some cases, whether we survive at all. Throughout Earth’s history, climates have changed, sometimes quite slowly, other times rather abruptly. In either case, the survival of the species living in those times depended on their ability to adapt to the new climate—sometimes in a rather short period of time. Those who could not adapt became extinct.

The human species is no exception, albeit our intelligence makes us one of the most adaptable species to ever walk on Earth. The real question is how quickly and how well modern civilization—our institutions, our governments, our communities, our food production and transportation systems—can adjust to the changes a new climate will bring.

**WHAT IS “CLIMATE”?** In a word, climate is the weather—the expected range of temperatures, precipitation, humidity, sunshine and windiness in a particular part of the world at a given time of year. The dictionary definition of climate is that it’s the pattern of weather measured and averaged over a 30-year span for a particular region and period of time.

Many factors determine the climate of a region, including its distance from the equator, its terrain, the amount of sunshine it receives, its elevation above sea level, and how close it is to an ocean or other large body of water.

**WISCONSIN CLIMATE 2000** Wisconsin has what is called a continental climate, modified somewhat in coastal areas by two of the largest lakes in the world. Averaging about 1,000 feet above sea level and halfway between the equator and the North Pole, our state historically has had cold, snowy winters and warm summer days with cool summer nights.

In northern parts of the state, temperatures 30 degrees below zero or colder occur almost every winter. Usually snow covers the ground and the lakes are frozen over statewide all winter long. In southern parts of the state, average daytime *high* temperatures are generally below freezing from early December through late February. We expect temperatures to top 90 degrees fewer than 14 times a year, and in the central lowlands it's not unusual for temperatures to dip below freezing even in summer.

Our average annual precipitation is around 30 inches, about two-thirds of it falling as rain during the growing season. We get around three dozen or so thunderstorms most years, sometimes with strong winds and hail, and once in a while with tornadoes. Ice storms are relatively rare, occurring somewhere in the state less than once every three years or so.

That's been our climate since the state was created in 1848, and it's what makes Wisconsin a special place for enjoying a wide variety of winter sports, including ice fishing, cross-country skiing, snowmobiling, sled dog racing, tobogganing, snowshoeing and ice hockey. It's an ideal climate for dairy farming and growing vegetables, corn, hay and soybeans. It's also why trout and other cold-water species of fish populate our lakes and streams, and white and red pine and quaking aspen thrive in the North Woods. It's what makes Wisconsin, well, Wisconsin.

Now it is clear our climate is changing, and the forecast for our part of the world says our grandchildren will likely live in a very different Wisconsin 100 years from now. In fact, our climate is likely to become noticeably different within the lifetimes of most adults alive today. If you look closely, you can see it changing already.

**EVIDENCE OF CHANGE** Thermometers are simple but trustworthy devices, and they are telling us that mean temperatures in the upper Great Lakes region have gone up nearly four degrees over the last century. About two-thirds of that increase was recorded just within the last 30 years—which, by dictionary definition alone, means we are already living in a different climate.

Perhaps the single most elegant proof of this four-degree change comes from the Center for Limnology (the study of lakes) at the University of Wisconsin-Madison, which maintains a record of the dates when Lake

Mendota freezes over and the ice cover breaks up each year that goes back more than 150 years. This record shows that the 10 longest periods of ice cover all occurred more than 100 years ago, while seven of the 10 shortest ice covers all happened inside the last 50 years—the four shortest ever within the last 25 years. When averaged, this record shows a long-term downward trend in the length of time that Lake Mendota is ice covered to where it is now 19 days shorter than a century ago. In a typical winter these days, the ice lasts just three months compared to four months 150 years ago.

And it's not only Lake Mendota. Similar records show almost identical trends in the freeze and break-up dates of the ice cover on lakes across the entire state, from Lake Geneva in southeastern Wisconsin to Shell Lake in the northwestern part of the state. Much older ice cover records in Finland, Russia and Japan also show the same thing is happening on lakes all across the Northern Hemisphere.

Plenty of other evidence—both scientific and anecdotal—indicates our Midwestern climate is changing. Dozens of scientific studies show many species of mammals breaking hibernation earlier and shifting their ranges northward. Records kept at Aldo Leopold's cabin near Baraboo show that migratory geese are returning a month sooner and plants are blooming over a week earlier than they did 70 years ago. Residents of the Duluth-Superior area say they were unaccustomed to seeing nesting cardinals and tomatoes turning red before the first killing frost of fall—but no longer. All of these are indications of a changing climate, of shorter winters and warmer summers.

**WISCONSIN CLIMATE 2100** In the coming decades, Wisconsin's climate is expected to become warmer and drier, especially in the summer. Before the century ends, *average* summer temperatures are projected to increase by as much as 8 to 18 degrees and *average* winter temperatures will rise 6 to 11 degrees. In both cases, the larger rise in temperature will occur in northern parts of the state. That may not seem like enough of an increase to really notice until you realize that, in southern parts of Wisconsin, an 8-degree increase in temperature would push average daytime highs from the low 80s to 90 degrees or higher for 31 days each summer and nudge it above the freezing mark all winter long.

Wisconsin's average annual amount of precipitation is not expected to change much, but our summers are expected become drier as warmer temperatures increase evaporation and seasonal precipitation patterns shift. Winter precipitation is projected to increase by as much as 30 percent, while summer precipitation may decline as much as 20 percent. As the amount





Dave Rieks, Illinois-Indiana Sea Grant

water vapor in the atmosphere increases with global temperatures and warmer ocean waters, the air will become more humid. This means when it does rain or snow, it's likely to be in large amounts.

All of this means we can expect an increase in extreme heat waves and more frequent droughts in summer. At the same time, severe thunderstorms may double in frequency, increasing the amounts of damage caused by heavy rainfall, hail and strong tornadoes. The winter season is likely to be punctuated with increasingly frequent mid-winter thaws, freezing rains and ice storms, and flooding. We may expect heavier snowfalls, especially over the next few decades, yet the average length of time the ground stays snow covered and our lakes remain ice covered will shrink with each passing decade.

**SOME POSITIVES, MANY NEGATIVES** On the plus side, a warming climate during the first half of this century means lower winter heating costs, much longer frost-free growing seasons and better yields of some crops. It will also improve forest growth and expand the range and populations of resident species of birds, small mammals, reptiles, and warmwater fishes. Waterborne commerce will enjoy longer ice-free shipping seasons on the Great Lakes and Upper Mississippi River. Winter recreation may suffer, but summer recreation could boom.

On the minus side, as the climate continues to warm in the second half of the century, it will bring greater summer cooling costs, more frequent ozone alerts, and longer, more intense heat waves. Over time, the benefits of a warming climate for agriculture may be outweighed by the adverse effects of declining soil moisture and more frequent droughts, severe storm and erosion damage, and a northward invasion of various warm-climate crop pests and pathogens. The need to irrigate crops and greater urban demands for water will strain groundwater supplies in some areas. Warmer conditions will also invite invasions of chiggers, fire ants and numerous other kinds of insects previously unknown here. Populations of disease-carrying insects could swell and spread, and outbreaks of infectious diseases like West Nile virus may increase.

Greater evaporation due to generally warmer temperatures and less winter ice cover are expected to cause Great Lakes water levels to decline several feet, threatening coastal drinking water supply systems as well as waterborne commerce, and causing shipping, dredging and harbor adjustment costs to rise. Barge and train traffic through the Upper Mississippi River Valley could be interrupted alternately by low summer-fall stream flows and winter-spring floods. Warmer water temperatures and increased stormwater runoff will reduce the water quality of many inland lakes and rivers as well as Great Lakes coastal waters.

Longer, hotter, drier summers and faster evaporation will result in warmer and shallower rivers, shrinking wetlands, and dried-up streams, flowages and wild rice beds. Algae blooms will create anoxic conditions for aquatic life in ponds and many lakes. These conditions will eliminate much the habitat available for trout and other cold-water fishes, amphibians and waterfowl. Hot dry conditions, coupled with more severe thunderstorms and lightning, will increase the chance of forest fires, and red pine and spruce trees will disappear from our northern forests.

**THE SCIENTIFIC CONSENSUS** These projections for Wisconsin's future climate are but a microcosm of the most recent global climate forecast produced by the Intergovernmental Panel on Climate Change (IPCC), a scientific body established in 1988 by the World Meteorological Organization and the United Nations Environment Program to provide decision-makers with an objective source of information about climate change. Its role is to provide a comprehensive assessment of the latest scientific information available worldwide about the risks of human-induced climate change, its observed and projected effects, and options for dealing with the change.

One of the most notable aspects of the 2007 IPCC Fourth Assessment Report—which concludes that “warming of the climate systems is unequivocal” and “sea level rise under warming is inevitable”—is that this represents the *consensus* findings of nearly 4,000 of the world’s leading experts on climate and climate change. It is the product of more than 450 authors and 800 contributing authors from universities, research centers, and business and environmental associations from all over the world, whose work was then reviewed by more than 2,500 other scientific experts to ensure that it represented an objective and complete assessment of the latest scientific information available.

“Consensus” means all of these scientists are in general agreement on every finding presented in the report. Moreover, IPCC reports also must be accepted and each “Summary for Policymakers” approved by all IPCC government sponsors, which includes the United States, before they are released.

Consensus also means that anything on which there is *not* general agreement is omitted. In other words, IPCC reports present only the established, mainstream scientific viewpoint. So—as alarming as many findings in the latest IPCC report are—it is a relatively conservative assessment. If anything, the IPCC report most likely understates the problem.

**COULD IT BE WORSE?** Human knowledge is limited, particularly with regard to how our climate works. We know that climate changes do occur—the Ice Ages alone prove that—but up to a century ago conventional scientific thinking was that such changes occurred gradually, over tens of thousands of years. In the 1950s, scientists found evidence of climate shifts that had taken place much more rapidly, within a few thousand years. Further research indicated climate changes could occur in less than a century; today, we have evidence that, once certain “tipping points” are reached, dramatic climate changes can occur in less than a decade. Even the IPCC’s report acknowledges that “warming could lead to some impacts that are abrupt or irreversible.”

One scientific scenario that has received considerable attention in the media and science-fiction movies is that rapid melting of the polar icecaps and Greenland glaciers—besides causing a rapid rise in ocean water levels and massive coastal flooding—could shut down the thermohaline “North Atlantic conveyor” of tropical ocean water that keeps northern Europe’s climate warmer than Canada’s, thereby triggering another Ice Age (a distinctly unpleasant prospect for Wisconsin). However, the IPCC report states that,

while the thermohaline conveyor will “very likely” slow down over the next 90 years, it is “very unlikely” that it will undergo an abrupt change; thus, the climatic forecast for Europe remains “warmer.”

A scenario proposed by some scientists is that a rapid rise in ocean temperatures and Arctic melting could thaw deposits of methane hydrates (an ice-like substance consisting of frozen methane and water) that lie beneath the ocean floor and arctic tundra, thereby releasing large amounts of methane gas into the atmosphere. Because methane is 21 times more effective at trapping heat than carbon dioxide, this could greatly accelerate global warming, which would melt increasing amounts of methane hydrate—the largest reservoir of organic carbon on Earth—and cause runaway global warming. There is evidence such an event happened at the end of the Permian 250 million years ago, triggering the largest mass extinction in Earth history, when 70 percent of all terrestrial life and 95 percent of sea life perished.

**WHAT CAN WE DO?** Natural and human history both tell us that the ability of people, plants, animals, ecosystems and civilizations to adapt to changes in climate largely depends on how much and how rapidly change occurs.

Until we minimize human carbon dioxide emissions, global temperatures are certain to continue rising, because all the carbon dioxide we are adding to the atmosphere will remain there for the next 50 to 100 years. Therefore, anything and everything we can do now to reduce carbon dioxide and other greenhouse gases will help slow down the rate of climate change, reduce the magnitude of change in the future and help improve our ability to adapt.

Finally, the most important thing each of us in Wisconsin can do to protect ourselves, our families and loved ones is to heed the warning of impending climate change and prepare for it. Anticipate and prepare for the possibility of severe summer droughts and extreme heat waves, severe storms, heavy rains and snowfall, record flooding and tornadoes. Also be prepared for any disruption to power, water and food supplies that these may cause.

It has always been wise to make such emergency preparations, but the expected and especially the unforeseen consequences of a rapidly changing climate will make such preparations all the more important in the years ahead. Our lives, our fortunes and our way of life may depend on it.

—Stephen Wittman



# WHAT EACH OF US CAN DO TO HELP:

## Money-Saving, No-Cost Solutions

**Use less electricity.** More than half the electricity in the United States comes from coal-fired power plants, which are the world's largest single human source of carbon dioxide emissions. Turn off lights you don't need and unplug appliances you're not using.

**Use less gasoline.** Automobiles are the second-largest human source of greenhouse gases. Every gallon of gas we use releases 25 pounds of greenhouse gases into the atmosphere. Whenever possible, walk, bike, use public transportation or car pool instead of driving.

**Use less hot water.** Water heaters use large amounts of energy, producing carbon dioxide either directly (natural gas) or indirectly (electric).

**Eat less meat.** Cattle are a major source of methane gas, which traps 21 times more solar heat than carbon dioxide. Worldwide, cattle and other ruminant livestock produce over a fifth of all methane emissions from human sources. Moreover, feed grain production and delivery also consume a lot of petroleum, and the nitrogen fertilizers used to grow livestock feed are significant sources of nitrous oxide, a greenhouse gas that absorbs 310 times more heat than carbon dioxide.

**Consume less.** Most products today are transported long distances by trucks, trains, ships or planes that burn significant amounts of fossil fuel.

**Generate less garbage.** About half of all landfill gas emissions is methane from decaying organic household wastes.

## If You Can ...

**Buy locally produced goods and/or organically grown foods.**

**Buy American-made products over those imported from overseas.**

**Invest in and use renewable sources of energy.**

**Plant trees—lots of them.**

## Solutions That Cost Now But Save Money in the Long Run

**Get a car with better fuel economy.**

**Replace old electrical appliances with more energy-efficient ones.** Refrigerators, freezers, air conditioners and water heaters are the biggest users. Look for the Energy Star.

**Install a programmable thermostat for your furnace**—or turn your thermostat down a few degrees in winter and up a few degrees in summer.

**Replace incandescent light bulbs with compact fluorescent light bulbs,** especially in frequently used lighting fixtures.

**Request a home energy audit from your local utility and weatherize your home.** Place extra insulation in the attic and install energy-conserving multi-pane windows.

## Big Picture Solutions

**Let your elected officials and policymakers know you are concerned about climate change.** Encourage them to support immediate, significant reductions in U.S. greenhouse gas emissions and the rapid development of alternatives to using fossil fuels.

**Support global population control.** Over the last 150 years, the human population has grown from 1.2 billion to about 6.8 billion, adding nearly 80 million annually. This burgeoning population is contributing ever-increasing amounts of greenhouse gases to the atmosphere every day through the burning of a massive amount of fossil fuels, deforestation and intensive agriculture. In the final analysis, global warming is the result of human pollution.







Native plant, hairy sweet cicely : U.S. EPA Visualizing the Great Lakes / Lake Superior shoreline: Dave Hansen, Michigan Extension Service



**A GLOBAL COMMONS** Our atmosphere is a “global commons”—something held and shared by everyone on Earth. As manned balloon flights have shown, the air over one place can be halfway around the world a week later. The air over China is traveling over the United States a few days later and in five days is over Europe.

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The atmosphere is used by everyone as a dumping ground for all sorts of pollution. While most particulate pollutants fall out of the atmosphere relatively quickly, some gaseous pollutants can remain in the atmosphere for a long time. Eventually these can accumulate to the point where they begin to change the chemical composition of the atmosphere. It is this kind of pollution that is causing global warming.

The other global commons, the ocean, has the International Law of the Sea. It’s not a particularly strong law, but it includes some regulations designed to stop pollution and protect the ocean from being used as a dumping ground. There is no such law for the atmosphere.

## GLOBAL WARMING IS UNEQUIVOCAL

*Based on the Keynote Presentation by Kevin Trenberth, Senior Scientist, National Center for Atmospheric Research, and Member of the Intergovernmental Panel on Climate Change*

**RISING CARBON DIOXIDE LEVELS** Among the evidence that the composition of the atmosphere is changing is the record of carbon dioxide levels kept since 1958 at Mauna Loa, Hawaii. This record shows what could be called the breathing of our planet. The amount of carbon dioxide in the air normally decreases by about five parts per million in spring and summer when it is “inhaled” for photosynthesis by trees and other plants as they bloom and grow. Then it increases by a similar amount again in autumn and winter as it is “exhaled” by decaying plants and tree leaves. The Mauna Loa record shows a steady increase in the amount of carbon dioxide in the air to where it is now about 65 parts per million more than it was 50 years ago.

Carbon dioxide has a long atmospheric lifetime—more than 100 years—so it is the ever-increasing amount of carbon dioxide accumulating in the air from deforestation and the massive amounts of carbon-laden coal and petroleum we’ve burned over the past century that matters most in terms of what is causing the climate change we are seeing today.

From 1850 to 2004, the United States was the largest single source of fossil-fuel carbon dioxide emissions in the world—nearly as large as the combined total for all European nations—followed by Russia, China, India and rest of the world. While the United States is still largest single source today, by 2004 both China and India had more than doubled their shares of the total amount of carbon dioxide emitted from human sources. Within three or four years, China’s percentage of total emissions is estimated to surpass that of the United States.

Another way of looking at this is per-capita emissions. Again, Americans lead the world in the amount of carbon dioxide emitted per person, while the average European contributes less than half as much. Why is that? One reason is that gasoline in Europe costs eight or nine dollars a gallon, electricity costs a lot more, and so people use less of both. It’s been shown that if the cost of gasoline goes up 10 percent, amount consumed goes down three percent.

China’s per-capita emission rate is about a tenth of ours, but more of its people are using cars and electricity, so its total emissions are going up rapidly. Similarly, because of its massive population, emissions from India are growing despite a per-capita emission rate that’s one-twentieth that of the average American. To improve the standard of living for their citizens, China and India have been bringing one new coal-fired electrical power plant online every three days for the last five years.

**THE GREENHOUSE EFFECT** The so-called “greenhouse effect” is key to understanding the problem. Without heat-trapping gases in the atmosphere, Earth would be too cold to sustain life as we know it. The composition of this “gas greenhouse” is about 60 percent water vapor, 26 percent carbon dioxide, eight percent ozone, six percent nitrous oxide and methane, and less than one percent other trace gases.

As the sun’s radiation reaches Earth, some is deflected by the atmosphere or reflected back into space by clouds and snow, but most of it is absorbed by the ocean and continents, warming them. This warmth then radiates back out into space, but as it passes up through the atmosphere much of it gets detained by clouds and the greenhouse gases. This is what keeps Earth’s surface and the lower atmosphere warm.

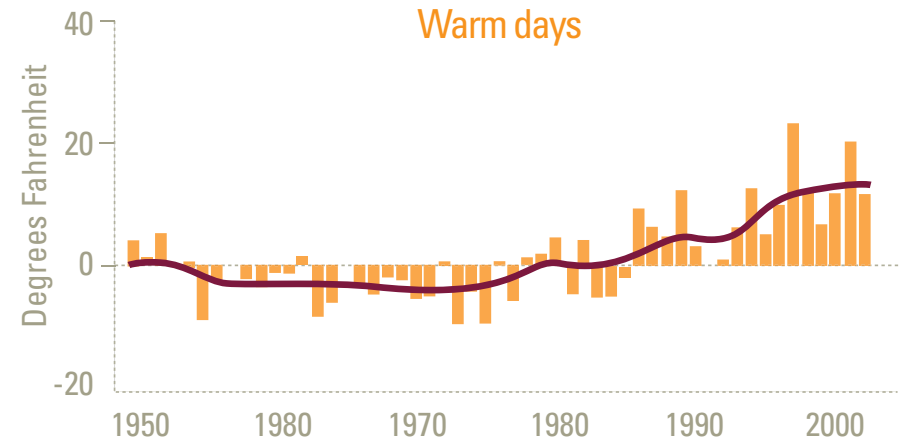
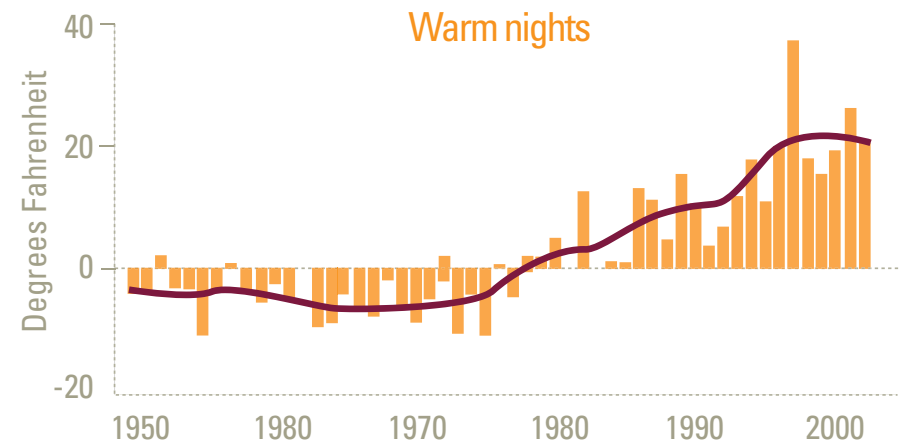
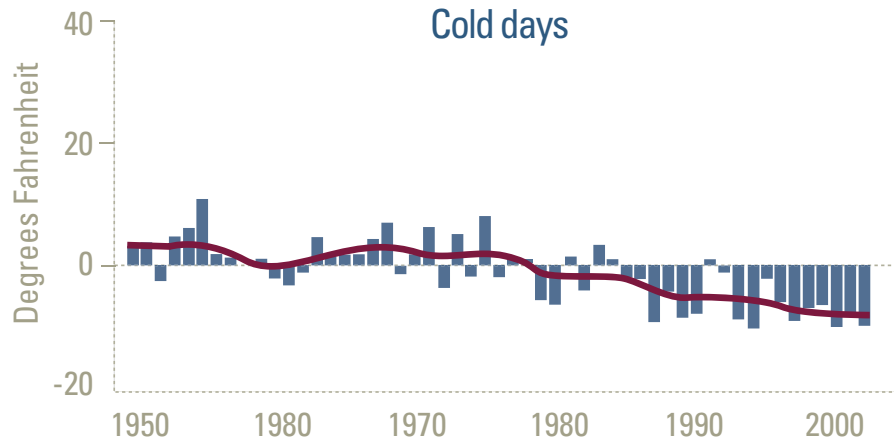
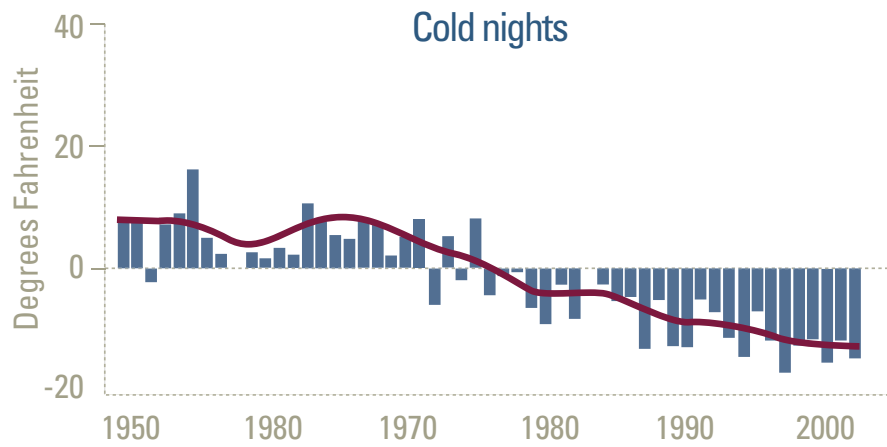
The amount of incoming energy from the sun amounts to about 175 petawatts, or 175 million billion watts, of which about 120 petawatts is absorbed by our planet. This is the equivalent of 120 million of the biggest, thousand-megawatt electrical power plants we have today. This tells us:

- Direct human influences are tiny compared to those of nature.
- The primary way human activities can affect climate is by interfering with the natural flow of energy, such as by changing the composition of the atmosphere.

And the rapid increase in the amount of carbon dioxide and other greenhouse gases from human activities is changing the composition of the atmosphere, and this is adding to the natural greenhouse effect.

**TEMPERATURES RISING** Over the last 30 years, the effects of this change in atmospheric composition have really emerged from the background noise of natural variability. Since 1970, we have seen a worldwide rise in temperatures in the lower atmosphere, both over land and in the ocean. We have also seen a worldwide rise in ocean water levels, water vapor, precipitation north and south of the tropics, and rainfall intensity. Hurricane intensity, drought, extreme high temperatures and heat waves have also increased. At the same time, we have seen a decrease in cold temperatures, snow cover in the Northern Hemisphere, arctic sea ice and glaciers.

Global mean temperatures are rising faster with time. The mean rate of temperature rise for the last 150 years works out to about 0.08 degrees Fahrenheit per decade. Over the last 50 years, the rate increased to 0.23



Source: Alexander et al., 2006

degrees per decade, and the mean rate over the last 25 years has been 0.32 degrees per decade. As a result, we have seen a sharp rise over the last 30 years in both land and sea surface temperatures, with land surface warming faster than the ocean surface. This increasingly upward trend explains why the 12 warmest global mean temperatures on record have all occurred since 1990.

Ever notice that when the sun comes out after a rain shower, the puddles all dry up before the temperature increases? Just as the human body uses sweat to control heat, Earth uses water vapor. Warmer temperatures cause the air to retain more water vapor—about four percent more for each degree Fahrenheit rise in temperature. Since 1970, we have observed a one degree rise in surface and lower atmosphere temperatures over the ocean, and we measure four percent more water vapor in the air. Not only is this enhancing the greenhouse effect, it means more moisture in the air for precipitation.

**MORE RAIN, MORE DROUGHT** The annual amount of precipitation has been changing significantly over broad areas of land around the world since 1900. We see precipitation increasing in northern and eastern North America, northern and central Europe, Argentina, and northern Asia. Precipitation has decreased—notably within the last 50 years—in the Sahel Region of western Africa, northern and southern Africa, southern Europe and the Mediterranean Basin, and Southeast Asia. In general, it is becoming drier throughout Africa and the northern subtropics (20-35 degrees latitude), while it is getting wetter in higher latitudes (35-55 degrees latitude).

In the United States, total precipitation rose seven percent between 1900 and 2002 for all of the lower 48 states except in the Southwest. We have also observed a 14 percent increase in heavy precipitation and, more significantly, a 20 percent increase in very heavy (upper one percentile) precipitation, with an increasing frequency of both over the last 25 years or so. When it rains, it's raining harder now.





Hurricane Katrina: Globally, the number and percentage of intense hurricanes is increasing with the rise in sea surface temperatures.

Hurricane Katrina: NASA, Jeff Schmaltz, MODIS Land Rapid Response Team; Lake Powell: Lion de Belfort

It's much the same story at the nation's largest manmade reservoir, Lake Mead, also on the Colorado River about 30 miles southeast of Las Vegas, which gets most of its water from melting snowcaps on the Western Colorado Rockies. Since 2000, below-average snowfalls have caused a steady drop in Lake Mead's water level to where it is now down to half of full capacity.

The Palmer Drought Severity Index (PDSI) combines rainfall and temperature together as an indicator of the total supply of water and also the effects of evaporation and drying associated with higher temperatures. The PDSI indicates that climate change due to rising greenhouse gases is not only causing wet areas to become wetter, but dry areas to become more arid. Water management—dealing with how to save in times of excess for times of drought—will be a major challenge in these areas in the future.

**MORE HOT SPOTS** Temperature extremes have been changing across large parts of most continents. Recently, researchers looked at the very low temperatures and very high temperatures—those in the top and the bottom five percentile. They found that, since 1950, cold nights are becoming fewer everywhere, and cold days are becoming fewer in most places, except in the eastern United States. Warm nights are increasing and more common everywhere, and warm days are increasing most places, though not in southern Greenland, Argentina and the eastern United States.

Most other places around the world are also showing an increase in heavy rainfall, and this is related to the increase in water vapor in the atmosphere. Another significant change is the character of this precipitation: More is falling as rain than as snow, especially in the fall and spring, resulting in less winter snowpack in many mountain and continental areas where it is important to the water supply. Coupled with warmer temperatures, which are causing the snowmelt to occur faster and sooner in the spring, this results in less soil moisture when summer arrives, increasing the risks of drought and wildfires substantially.

One symptom of this can be seen in one of the largest manmade reservoirs in the United States, Lake Powell on the Colorado River along the Utah-Arizona border. A drought began in 1999 that has reduced Lake Powell's water level more than 100 feet below its high water mark. Its water levels declined steadily through November 2004, when an El Niño event brought rains that provided some short-term relief, but the hydrological drought has not gone away.



Aerial photo of Lake Powell taken in May 2007. Note the prominent "bathtub ring" left by the dropping water level.



The increasing number of warm days is causing an increase in heat waves around the world, such as the extreme heat wave in the summer of 2003 in Europe that killed 70,000 people. Europe has had a generally upward trend in June-July-August temperature anomalies since 1980.

The reason the eastern half of the United States and Argentina have been an exception to the warming is because they have two things in common: both are east of mountain ranges (the Rockies and Andes, respectively), and both are east of the Pacific Ocean, downwind from where El Niño occurs. El Niño events in the mid-Pacific affect the flow of the high-altitude jet streams, which direct where storms go and rain falls. The reason average temperatures have not risen in these two regions is because of cloudy and wet conditions caused by El Niño.

**TROUBLED WATERS** Globally, the number and percentage of intense hurricanes is increasing with the rise in sea surface temperatures. The number of North Atlantic hurricanes and named storms has shown a marked increase since 1994 coinciding with the rise in sea surface temperatures.

The rate of sea level rise is also increasing with increasing seawater temperatures. The rate of sea level rise during 1993-2003 is nearly double the annual rate recorded over the entire 20th century. Since 1993, the global sea level has risen 1.6 inches, about 60 percent of which is due to the water expanding as it warms, the rest from melting glaciers.

The area of arctic sea ice has contracted at a rate of 2.7 percent per decade since the 1970s. Similarly, the area of the Northern Hemisphere still snow-covered in March and April declined five percent during the 1980s. The glacial melt zones in Greenland now reach much further inland and more than 6,500 feet above sea level.

**PREDICTING THE FUTURE** Scientific models of the climate system are designed to take into account all of the key factors and the many variables that affect Earth's climate. They are then tested against measurements and observations of past climate, refined and retested, and fine-tuned until they can simulate actual climate behavior in the past. Most of the climatic changes observed over the last 50 years are now closely simulated by our climate models, and this increases our confidence in these models to make future projections.

For example, a run of the climate model starting in 1890 and using only natural factors, like volcanic activity and changes in solar radiation, indicates a global average temperature that should have been much lower than

what we've seen since the 1970s. It is only when the model includes the measured increase in carbon dioxide and other changes in the composition of the atmosphere from human activities that it closely approximates the observed rise in the global average temperature over the last century—especially during the last 30 years of that century.

Run forward in time, climate and carbon cycle model simulations indicate temperatures over land areas will increase more rapidly than over the ocean, and the greatest degree of warming will occur in the polar areas and the high northern latitudes, where median temperatures could rise by more than 14 degrees over the next 300 years if fossil fuel use continues at present rates.

Projected patterns of precipitation change over the course of the 21st century show that the patterns observed in recent years are likely to continue into the 2090s, with precipitation increases of more than 20 percent very likely in the high northern latitudes, while most subtropical regions will likely experience similarly large decreases in rainfall.

**WARNINGS FROM THE PAST** Analysis of Antarctic ice cores has found remarkable parallels in the rise and fall in carbon dioxide and methane concentrations and ambient temperature during the last 420,000 years. The ice core record indicates that continental glaciers take tens of thousands of years to develop, yet it appears they melt very quickly with an abrupt climate change at the end of each ice age. The cause is still under investigation, but this may have very important ramifications for rapid melting of the Antarctic glaciers and the potential for a relatively fast and large rise in sea level.

Ice ages and the warm periods between them are both caused by subtle changes in the Earth's orbit around the sun—orbital roundness (eccentricity), the tilt of Earth's axis (inclination) and how close the poles are to the sun during winter and summer (precession).

Antarctic ice cores show that atmospheric concentrations of carbon dioxide and methane—a greenhouse gas 20 times more potent—are timed exquisitely with rising and falling Antarctic temperatures. This is because as the cold seawater warms, it gives off more carbon dioxide (like warm carbonated water), and warmth also increases biological activity, which generates more methane. Due to the greenhouse effect, rising levels of carbon dioxide and methane accelerate the warming, so the planet warms up relatively quickly. As it cools, the exact opposite happens, and cooling begets more cooling. These “positive feedback loops” are the crux of the science of global warming.

The ice cores tell us that atmospheric levels of carbon dioxide have varied from about 180 parts per million to around 280 parts per million over the last 420,000 years, and during that time Antarctic temperatures ranged from 50 below to 36 degrees above zero.

Today, atmospheric carbon dioxide levels have risen to 375 parts per million, and they are projected to reach a concentration of at least 550 and perhaps as high as 1,000 parts per million. Earth's climate system has not experienced such high levels of carbon dioxide in more than a million years, and this is why climate scientists are so concerned.

Members of the Intergovernmental Panel on Climate Change are not absolutely certain about exactly how our climate will change, but they are certain it is changing—and that the changes it brings could be very disruptive and extremely costly to people throughout the world.

Lake Mendota: Jeff Miller, UW-Madison University Communications



**DEALING WITH CHANGE** In his book *Collapse: How Societies Choose to Fail or Succeed*, Jared Diamond describes four common ways that societies and even entire civilizations have collapsed in the past:

- They fail to anticipate a problem before it arises.
- When the problem arises, they fail to perceive it.
- After they perceive the problem, they fail to try to solve it.
- When they try to solve it, they do not succeed.

Each of these has parallels to the ways that many governments and individuals around the world have been responding to the problems posed by climate change.

## SEEING CLIMATE CHANGE IN WATER

Based on a presentation by John Magnuson, Emeritus Professor of Zoology and Limnology, University of Wisconsin-Madison, Member of the Intergovernmental Panel on Climate Change



**A MINER'S CANARY** Every fall, the Center for Limnology (lake science) at UW-Madison posts a graph of the date each winter when Lake Mendota has frozen over in the past, and everyone at the center gets a chance to guess when it will occur in the coming winter. Few even came close last winter (2006-07), when the lake did not freeze over until January 20—the second latest date in the center's 150 years of records.

The center's ice-on, ice-off records go back to the 1850s, when they were started by early settlers and Madison residents because the lake's ice was important to them—it was harvested for local use in early “icebox” refrigerators, and after the railroads arrived in the late 1800s, lake ice became a commodity that was shipped as far away as New Orleans.

This lake ice record shows that in the 1850s Lake Mendota was frozen over for about four months each winter. By the early 2000s, however, the ice cover lasted an average of just three months a year. In other words, the amount of time the lake is ice-covered is nearly 25 percent less than it was 150 years ago. If this trend continues, the time will come when Lake Mendota will be ice-free all winter long.

Canaries were once carried into coalmines as an early warning of the presence of poisonous gases: because of their small size, they would succumb to any gas in the mine long before a human was affected. In this sense, the shrinking duration of Lake Mendota's ice cover is like a woozy miner's canary, because if the massive glaciers covering Greenland and Antarctica experience a similar 25 percent reduction in ice, the resulting rise in ocean water levels will flood many coastal areas of the United States, creating millions of climate change refugees from New York City, San Francisco, southern Florida and the Gulf Coast.

People have a tendency to remember most the recent past, which makes it hard for us to recognize and deal with something as gradual as climate change. Without a long-term written record or some mental reference, we lack the context to notice what's changed and end up living in what Magnuson called “the invisible present.”

A related concept is “the invisible place,” where we tend to think of what is happening to Lake Mendota, for example, as something that is happening only in Madison, so we may fail to see it as something that's occurring throughout our state and perhaps around the world.

**MELTING ICE RECORDS** A few years ago, Magnuson began looking at the long-term ice cover records for five other Wisconsin lakes and found the same trend of later ice-on and earlier ice-off dates. He and his colleagues then looked at ice records from around the world and found almost identi-

Lake Mendota: Jeff Miller, UW-Madison University Communications



cal trends throughout the Northern Hemisphere—in Canada's Northwest Territory, Finland, central Russia and Japan.

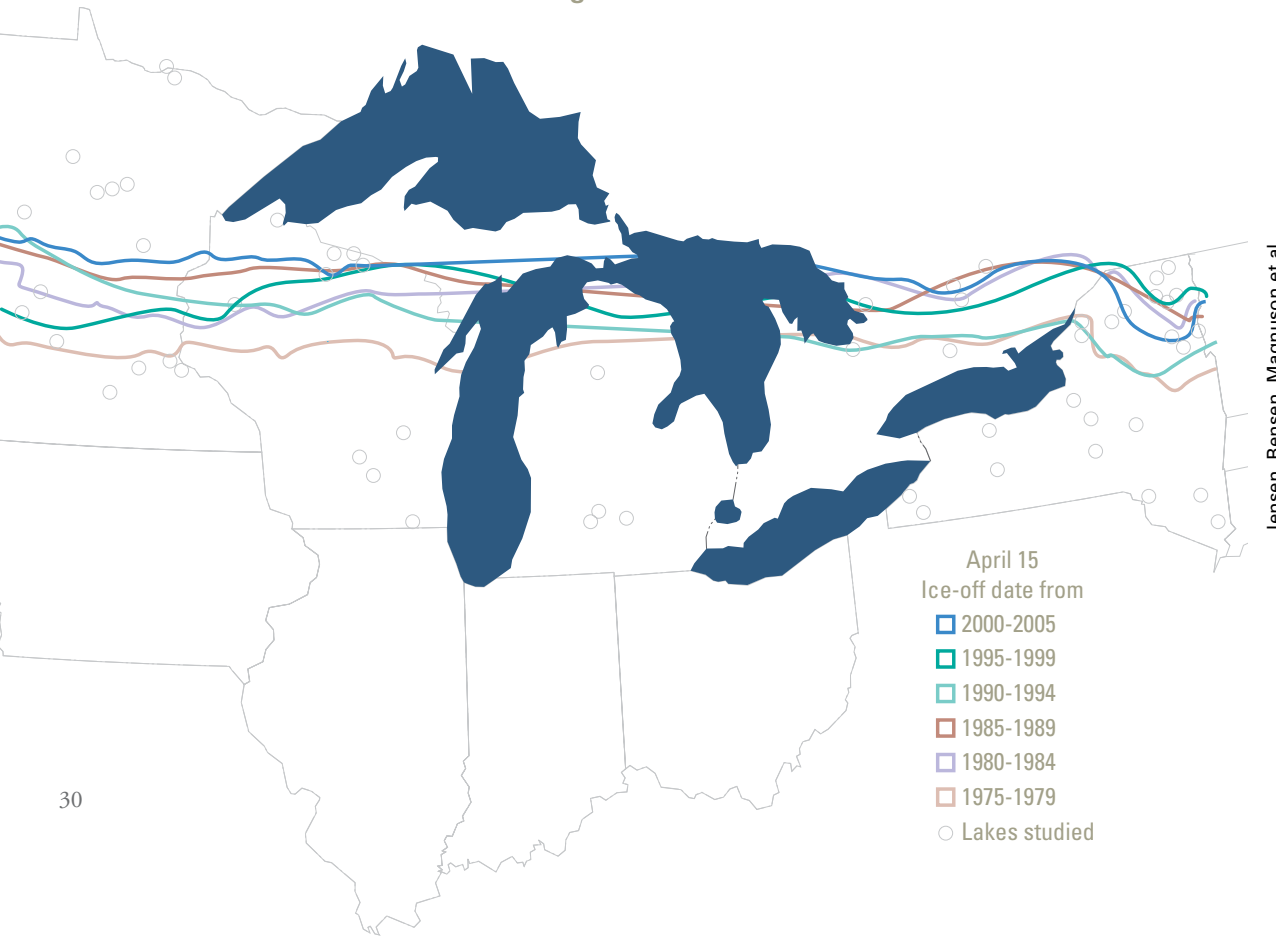
Priests at a Shinto shrine in Suwa Ko, Japan, maintain a record of ice on Lake Suwa that goes back nearly 600 years. From 1443 to 1825, these records show that the length of time the lake was ice-covered was getting about one day shorter per century; from 1800 through 1993, however, the duration of ice cover was shrinking at a rate of 19 days per century—identical to the rate measured at Lake Mendota.

When the change in average winter air temperature in the Northern Hemisphere over the last 150 years is compared with the average duration of ice cover on 17 lakes around the world during that time, the correlation between the rising air temperature and shorter periods of ice cover is clear. It also shows the rise in temperature and rate of decline in ice cover has accelerated since 1975.

In Wisconsin, the air temperature record also shows an accelerating rate of increase. From 1895 until about 1975, the temperature was increasing at a rate of 0.04 degrees Fahrenheit per decade; from 1975 through 2005 it was increasing at an average rate of 0.7 degrees per decade. During the same 30-year period, the average ice-off dates for Wisconsin lakes were arriving 3.3 days earlier each decade. Ice-on dates are arriving the same number of days later, so Wisconsin lakes are presently losing about a week of ice cover every 10 years.

Lakes in northern Wisconsin near Ashland and in Vilas County are losing an average of five to six days of ice cover per decade, while lakes in

## Northward migration of warmer climate



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southern Wisconsin—like Lake Geneva, Lake Mendota and Big Green Lake—are losing an average of nine days of ice cover each decade. That’s an extremely rapid rate of change.

**GIVING MEANING TO NUMBERS** Numbers and statistical statements like “average summer temperatures eight to 18 degrees warmer” and “extreme rainfall events 50-100 percent more common” generally don’t mean a lot to most people. In *Confronting Climate Change in the Great Lakes Region*, a report published in 2003 by the Ecological Society of America and the Union of Concerned Scientists, the coauthors (including Magnuson) decided to use temperature and precipitation gradient maps of the present climate of the United States as a way of conveying more vividly what future climate projections mean for Wisconsin and other Great Lakes states.

This exercise showed that by 2030 summers in Wisconsin would be more like those in Illinois today, and by 2095 our summers would closely

resemble those of present-day Arkansas and our winters would be like Iowa’s. For Illinoisians, summers in the future are likely to be like living in eastern Texas today.

Minnesota offers a particularly dramatic example of climate change. By the 2090s, summer temperatures and precipitation in Minnesota are expected to resemble the hot, relatively dry summers of present-day Kansas. This poses a serious threat to many species of Minnesota’s native plants, wildlife, trees and fish, which aren’t found in Kansas because the climate simply isn’t suitable for them to exist there.

Empirical evidence clearly shows this northward migration of warmer climate is already occurring. A line drawn on a map connecting Midwestern lakes with April 15 ice-off dates in 1975 would run from Minneapolis through Wausau to Grand Traverse Bay on Michigan’s Lower Peninsula. By 2004, that same line was running from Mille Lacs, Minn., through Hurley-Ironwood and across Michigan’s Upper Peninsula.

**COLD FISH, NO FISH / WARM FISH, MORE FISH** Fishes are often classified according to whether they prefer warm water, cool water or cold water. The white sucker is an example of a cool-water species of fish. Its thermal cousins include walleye, northern pike and yellow perch, three of Wisconsin’s most popular game fish. A study of where white suckers exist today and where they might persist 50 years from now in a much warmer United States showed a large reduction in the number of areas where this fish and, by inference, its cool-water cousins could survive—especially at lower elevations in states south of Wisconsin, but also in many waters here.

The story is a little different for lake trout and salmon in Lake Michigan, Lake Superior and Lake Huron, where some climate models indicate the depth and area of water within the optimum temperature range for these cold-water salmonids actually may increase. The Great Lakes will probably continue to serve as a southern refuge for trout, salmon and other cold-water fishes well into the next century.

However, the projected increase in temperatures accompanying the expected doubling of carbon dioxide levels during this century will move the thermal habitat boundaries for fish about 300 miles north of where they are today. This could exterminate cold- and cool-water fish populations south of the new thermal habitat boundaries, and invasions by new warmer-water species of fish may wipe out other resident species. Because they are more vulnerable to warming, streams and shallow ponds will experience greater changes and losses in fish populations than deep lakes.

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**EFFECTS ON THE WATER CYCLE** Rising temperatures will accelerate the global water cycle. This means more droughts, more storms and more floods. Over the last 100 years, Wisconsin's average daily precipitation did not change much. Over the last 30 years, however, we've been getting an average of three more inches of rain annually than we did during the previous 30 years.

Over next 100 years, our winter precipitation is expected to increase by 30 percent while summer precipitation will decrease slightly under a scenario of continued high greenhouse gas emissions that triple the atmospheric concentration of carbon dioxide and cause a double-digit rise in average temperatures. Under a reduced emissions scenario (atmospheric carbon dioxide levels double before they start to decline), winter precipitation eventually returns to its long-term average and summer precipitation tends to increase slightly.

However, one thing that shows a marked increase under either scenario is a dramatic increase in both 24-hour and seven-day heavy rainfall events. It isn't until the last couple of decades of the century that the frequency of both events starts to drop under the low-emissions scenario. This leads to more stormwater runoff, more erosion and floods, which can have dramatic effects on the chemistry, physics and biology of our lakes, rivers and streams.

**EFFECTS ON GREAT LAKES WATER LEVELS** The present water levels of the three upper Great Lakes—Superior, Huron and Michigan—are running near their all-time record low levels. Lake Michigan has more than 100 years of measured water levels, yet this record shows no definite trend either up or down, so it's difficult to attribute the lake's present low water levels to climate change.

Lake Michigan's water level has oscillated by as much as six feet over the last 100 years. One climate model says the lake's mean water level will rise 18 inches above its historic average; another says it will be five feet lower. Whichever is the case, future water level oscillations will occur around that.

Just two natural variables really control Great Lakes water levels: the amount of precipitation and the rate of evaporation. The effect of human water consumption and diversions can be measured in inches. Warmer average temperatures are causing less ice to form on the Great Lakes in winter, which greatly increases evaporation. Less ice cover also causes a net increase in water temperature, which delays the formation of ice cover the following winter. As a result of this "positive feedback loop," Lake Superior is warming up at a faster rate than is the air above it.

Tomato leaf stoma: Dartmouth College



Increasingly warmer air temperatures and warmer water temperatures mean much higher evaporation rates. The projected regional increase in winter precipitation notwithstanding, the weight of evidence is that Great Lakes water levels generally will get lower.

**LEAVE IT TO LEAVES** Another major change in the water cycle may come from the underside of leaves. Leaves take in carbon dioxide through pores on their bottom side called stomata. The hypothesis goes like this: with more carbon dioxide in the air, plants don't need to have their stomata open as much to get all the carbon dioxide that they need for photosynthesis. If their stomata aren't open as much, they don't lose as much water through evapotranspiration. Therefore, plants become more water-use efficient, and this should leave more water in the ground. Some scientists believe that this is responsible for the increase in water flow being seen in many rivers on continents throughout the world.

We are also seeing increased water flow in Wisconsin. For example, the average base flow of the Grant River near Burton—which comes from groundwater, not runoff—has shown a step increase of nearly 50 percent since 1970. Many other streams and rivers in Wisconsin show the same thing. Around the state we've seen a step increase in water levels at many groundwater wells and several seepage lakes as well. However, we're also seeing a lot of variation in base flows and lake water levels. As some lakes flood their shores, others are drying up.

Across Wisconsin, lake levels in seepage lakes, average base flow in streams, total annual flow in streams and the groundwater level in wells have all gone up since early 1970s. This could be the result of the rise in the amount and intensity of precipitation we've been getting—and perhaps partly because our trees and other plants are consuming less water due to higher concentrations of carbon dioxide in the air.

**MANIFESTATIONS OF CHANGE** Short-term variations in climate are simply the vagaries of weather. Long-term trends are signs of climate change. What we're seeing here in Wisconsin—rising temperatures, shrinking periods of ice cover on our lakes, and increasing amounts of rainfall—are not just variations in our weather; these are long-term trends—the local manifestation of a changing global climate.

It is important that we recognize them as such and try to anticipate the myriad problems they pose, and then act to address the causes as well as the effects of climate change.



“Climate change is perhaps the largest looming public health challenge we face, certainly in the environmental health field.”

—Dr. Howard Frumkin, director, National Center for Environmental Health, 2006

**LOOMING PUBLIC HEALTH RISKS** For more than a thousand years, the atmospheric carbon dioxide level has stayed relatively stable at 280 parts per million. When Patz started working on climate change issues about 14 years ago, the carbon dioxide level had risen to 370 parts per million; today, it stands at 385 parts per million. Accompanying this rapid rise in heat-trapping carbon dioxide has been a rapid rise in the global average temperature. It is already warmer now than any time in the last 1,000 years, and temperatures are expected to increase five to 10 degrees Fahrenheit over the next 100 years. Temperatures may become warmer than at any time in the last 400,000 years.

## HEALTH RISKS OF A WARMER, WETTER WISCONSIN

Based on a presentation by Jonathan Patz, Associate Professor of Environmental Studies and Population Health Sciences, University of Wisconsin-Madison, and member of the Intergovernmental Panel on Climate Change



To summarize the problem, climate change has three main physical effects:

- Rising temperatures—more heat waves, stronger thunderstorms
- Rising sea level from melting ice caps and thermo-expansion of saltwater
- Hydrologic extremes—more floods, more droughts

So what does this mean for us and our health? Certainly we know about people dying from heat stress and cardio-respiratory failure during heat waves. The “urban heat island effect” occurs when sprawling cities with lots of black asphalt highways and concrete absorb the heat and hold it. So in the center of a large city, where the majority of people live, it’s going to be a lot warmer than it is on the outskirts of the city.

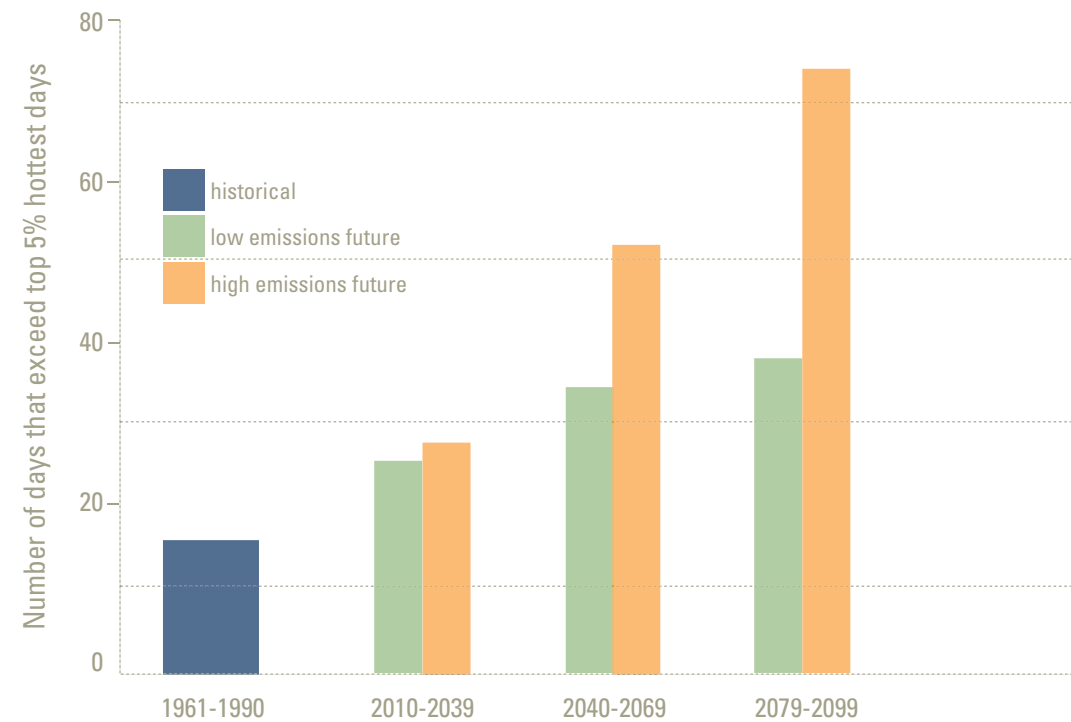
Other health effects of climate change include:

- Air pollution and allergens (asthma, chronic bronchitis, emphysema and other respiratory diseases)
- Vector-borne diseases (malaria, dengue, encephalitis, hantavirus, Rift Valley fever)
- Water-borne diseases (cholera, cyclospora, cryptosporidiosis, campylobacter, leptospirosis)
- Food and water supply (malnutrition, diarrhea, toxic Red Tides)
- Environmental refugees (forced migration, overcrowding, infectious diseases, human conflicts)

It’s the extremes of temperature and precipitation that most adversely affect people, and for Wisconsin the projected changes in extremes are for less cold weather and more hot weather, and more days with heavy precipitation.

With a STAR (Science to Achieve Results) grant from the U.S. Environmental Protection Agency, Patz is presently working with climatologists and Wisconsin public health officials to assess future climate change-related public health risks for residents of Wisconsin and the Chicago area.

**HEAT WAVES** Project climatologist Steve Vavrus at the UW-Madison Center for Climatic Research examined the changes in the number of extremely hot and cold days for southern Wisconsin using seven different



global climate change models. While there were some large differences in the models’ projections for the frequency of extremely hot days, all of them agreed that by the end of this century, southern Wisconsin can expect fewer cold days but many more hot days.

Moreover, the rise in degrees of temperature will be much larger on the hot side than on the cold side; in other words, extremely hot days will get much hotter than extremely cold days will be less cold. How much hotter it gets depends on how quickly and how much we reduce greenhouse gas emissions. While there is little difference in the short run, by the end of the century a low emissions scenario indicates we can reduce the number of extremely hot days by about half of what they will be under the scenario of continued high emission rates.

Either way, the projected increase in extreme heat poses significant public health problems. More than 70,000 people died in the heat wave that struck Europe in the summer of 2003. Temperatures during that heat wave were running about 40 degrees above normal, causing extraordinary electricity demand, difficulties cooling electrical power plants and numerous power outages. At Chinon, France, the temperature of the Vienne River topped 90 degrees.

We talk about being ready for such events, but are we really ready for extremes like that? We may have some surprises to deal with in extreme heat waves.

Global warming doesn’t just mean the thermometer is creeping up. Climatologists say it means greater variability, and greater variability is

extremely difficult to plan for. Rather than just the average temperature going up, we will have more frequent extremely hot days, more days topping 100 degrees. Adjusting to this type of variability could be the most difficult for us.

**AIR POLLUTION** When a heat wave occurs, it is usually accompanied by a stagnant air mass, and stagnant hot air can cause tremendous pollution problems. In the 2003 European heat wave, a quarter of the deaths in England were attributed to air pollution associated with the heat wave.

According to the Intergovernmental Panel on Climate Change, the severity and duration of summer air pollution episodes are projected to increase in the Northeast and Midwest regions of the United States by 2045-52 due to climate change-induced decreases in the frequency of low pressure (storm) systems—in other words, more stagnant air. By 2050, the IPCC warns that warming alone may increase the number of Red Ozone Alert days across the Eastern United States by 68 percent. This is referring to ground level ozone, or photochemical smog pollution, rather than the ozone layer high in the stratosphere that protects us from the sun's ultraviolet radiation. Ground-level ozone is extremely sensitive to temperature, so warmer temperatures may also mean greater health risks from higher ozone levels.

A study by UW-Madison's Tracey Holloway (currently under review) examined air pollution in Chicago under different climate model scenarios. Chicago averages three to seven days each year that exceed the U.S. Environmental Protection Agency's 84 parts per billion threshold for unsafe ozone levels. All six model projections say the number of days that ozone exceeds safe levels in Chicago is going to increase, although the models differ greatly on how many.

According to two of the models, the annual number of ozone red alerts in Chicago might frequently exceed 20 days by mid-century and average more than 20 days per year by the end of the century.

To make matters worse, some studies have shown that ragweed responds to warmer temperatures and more carbon dioxide in the atmosphere by producing more pollen. If the ozone season lengthens and goes into the spring, the combination of ozone and more pollen could worsen the situation for asthma sufferers.

**INFECTIOUS DISEASES** Global warming's greatest threat may also be the smallest. Mosquitoes are cold-blooded, which means their body temperature is the same as the air temperature. If a mosquito is carrying a nasty virus inside its body, air temperature can have a lot to do with the time it takes for that virus to develop inside the mosquito, which can result in more or less infectious mosquito bites. In general, when it's warmer, they become infectious more quickly. This is where a rise of one or two degrees in average temperature becomes important.

These cold-blooded insects carry lots of diseases, and one of the diseases spread by mosquitoes in this part of the world is West Nile virus. This is a zoonotic disease that cycles between mosquitoes and birds, but horses and people also can get infected, and for us it can be very serious.

West Nile virus arrived in the United States in New York in 1999 and has since spread across the country. It is believed to have spread so quickly because birds were carrying the virus up and down their migratory flyways on the Pacific and Atlantic coasts, across the Great Plains and along the Mississippi River.

Wisconsin had a large West Nile virus epidemic in 2002, when the summer average temperature was 10 degrees warmer than normal. The following summer was four degrees cooler than normal, and we had no epidemic. The reason for the 2002 epidemic was partly due to birds arriving here with the virus and partly because of the virus mutating into a more dangerous form, but some new research suggests that climate may have had something to do with it as well.

Recently published research on the strain of the West Nile virus that came into New York during the record-hot summer of 1999 found that its development requires warmer temperatures than other strains of the virus. The researchers also linked the West Nile epidemics in the summers of 2002-2004 to locations in the United States experiencing above-average temperatures, so health officials now think extremes in temperature may have something to do with modulating West Nile virus epidemics.

Common ragweed, *Ambrrosia artemisiifolia*: USGS







Culex mosquito: Jim Gathany, Centers for Disease Control

The common flood mosquitoes that appear after heavy rains generally are not carriers of West Nile virus. The primary West Nile virus mosquito belongs to the *Culex* genus of mosquitoes. These mosquitoes like dirty, concentrated water and thrive in hot drought conditions. In other parts of the world, heat waves and/or drought conditions have been associated with increases in the number of West Nile virus cases.

**EXTREME STORMS, FLOODS** Climate change is not just about warming, it's also about greater extremes in the hydrologic cycle. For much of the United States, global warming is expected to bring greater amounts of precipitation. Since the 1930s, a growing proportion of the United States has been indeed reporting much above-normal annual precipitation due to heavy rain, which is defined as more than two inches of rain in a day.

In a study of extreme precipitation and waterborne disease outbreaks in the United States during the 1948-94 period, Patz found that more than two-thirds of all outbreaks of waterborne diseases followed unusually heavy rains (above the 80th percentile), particularly surface water-related outbreaks. For example, the heaviest rainfall in 50 years preceded the 1993 cryptosporidium epidemic in Milwaukee, in which 405,000 people were exposed and 54 died.

Milwaukee is one of more than 900 communities in the United States that still have a combined sewer and stormwater system. Heavy rains can cause what are called combined sewer overflow events. This is not a new problem, and cities have been trying to clean this up, but it costs billions

and billions of dollars to redo a city's sewer and stormwater system. Climate change is expected to bring heavier rains with greater stormwater runoff, so bigger and more frequent combined sewer overflow events—which already discharge about 1.2 trillion gallons of sewage and stormwater each year—could become a serious public health problem in hundreds of communities.

Vavrus' climate research indicates the number of days with rainfalls totaling more than an inch are predicted to increase by 25 percent in Chicago by the late 21st century. Based on her Sea Grant study of stormwater contamination of Lake Michigan beaches, UW-Milwaukee's Sandra McLellan says that two inches is the threshold above which waterborne diseases and lots of contamination occur, so this could become another important public health issue in the future.

What we do to our landscape has a lot to do with our vulnerability to climate change. It can make things worse or better. As noted earlier, sprawling concrete cities with asphalt streets and highways can cause "urban heat islands." Hurricane Katrina was a disaster because of the size and power of the hurricane, but it was made worse because of the destruction of the Mississippi River delta coastal wetlands that once protected New Orleans.

**A MATTER OF ETHICS** There is also an ethical issue here. Hurricane Katrina was also a major social disaster, because it was mostly the poor people who couldn't get out of town, became stranded and died in the flood waters. There's a similar difference in who is most at risk from climate change. Climate change is a local problem, a regional problem and a global problem. How we behave and act locally can actually affect other people in our region and around the world.

Climate change is already contributing to deaths and disease around the world. Between 1970 and 2000, the World Health Organization estimates global warming caused at least 160,000 deaths and five million illnesses annually from malaria, diarrhea, malnutrition and flooding alone.

Climate-related mortality affects people in poor countries the most right now, especially in sub-Saharan Africa, but also in India and the Middle East. It is not an issue yet for nations in the Northern Hemisphere, who have been by far the biggest emitters of greenhouse gases and are most responsible for global warming. The people who have emitted the least amount of greenhouse gases are suffering the most.

Is it ethical that our energy policy and the way we live are contributing to deaths and disease around the world?

**MITIGATION AND ADAPTATION** People talk about mitigation mainly in terms of reducing the burning of fossil fuels. However, deforestation contributes about 20 percent to this problem. Trees absorb a lot of carbon dioxide, so when we cut down forests, we are actually making global warming worse. Earth has warmed already more than a degree in the last 90 years, and it's projected to keep getting warmer. We need to quit fueling the problem by burning fossil fuels and cranking out carbon dioxide. At the same, we need to try to protect our society from the warming that is expected to occur. We need both of these to happen at the same time.

The good news is that if we tackle the causes of global warming, we get lots of other benefits. About 800,000 people every year die from particulate air pollution. Burning gasoline or oil not only emits greenhouse gases and contributes to global warming, but it also releases particulate matter, which is the most dangerous form of air pollution. By reducing the burning of fossil fuels, we would not only reduce global warming but particulate air pollution as well.

Major efforts to do this are already underway around the nation and in Wisconsin as well. California Gov. Arnold Schwarzenegger has launched several major climate change initiatives to reduce greenhouse gases in that state. The mayors of more than 600 cities across the United States—including Mayor Dave Cieslewicz of Madison—have signed the “U.S. Mayors’ Climate Protection Agreement,” pledging to reduce their greenhouse gases emissions. Governor Jim Doyle has formed a Task Force on Global Warming to find ways to cut greenhouse gases with the goal of reducing Wisconsin’s carbon dioxide emissions 60 to 80 percent by 2050. The state Department of Natural Resources and UW-Madison also have formed a commission to look at this issue. Political will is growing, people are taking action, and change is starting to occur.

**A HEALTHY WAY TO FIGHT CLIMATE CHANGE** Climate change could be the greatest public health opportunity in more than a century in terms of Americans’ number one public health problem: being overweight. Two major factors in this problem are (1) the mass marketing and availability of junk food and “supersized” servings, and (2) a sedentary lifestyle.

It is estimated that two-thirds of Americans over age 20, plus 15 percent of those ages 6-19, are overweight. About seven percent of us—20.8 million people—have diabetes. Around 60 percent of American adults do not meet recommended levels of physical activity, and about 25 percent are completely sedentary.

Urban and neighborhood design that encourage sedentary lifestyles contribute to both obesity and greater greenhouse gas emissions. An example of this is an urban design that encourages driving and discourages bicycling and walking. According to the U.S. Department of Transportation, about 40 percent of all trips made by car are less than two miles long, which in most cases could be easily traveled by bicycle. However, drivers in most cities don’t expect to see bicyclists on the street and roadways, and many people are killed in bicycling accidents as a result. We need to redesign our cities to prevent that. Designing safer bicycle routes would help us reach a threshold level of enough bikes on the road such that seeing bikes becomes the norm, and fewer bicyclists would get hit.

The top six leading causes of death in the United States can be grouped as (1) heart disease, strokes and diabetes; (2) cancer and respiratory problems, and (3) unintentional injury, most cases of which are, respectively, the result of (1) a sedentary lifestyle and obesity, (2) air pollution, and (3) motor vehicle accidents.

Patz is involved in the “Triple-Win Bike Project,” which promotes bicycling over driving as a way to improve personal health through better physical fitness and at the same time reduce local air pollution and fight global climate change through reductions in greenhouse gas emissions.

Using Madison as an example, Patz said that if 20 percent of trips made by car were replaced with bicycling, it would reduce carbon dioxide emissions by nearly 17,000 tons a year and result in a 12 percent reduction in both ozone and nitrous oxide levels and a two percent reduction in particulate air pollution. That reduction in air pollution, in turn, would result in about 14,500 fewer acute respiratory cases and 2,000 fewer asthma admissions annually, which would save \$40 million in health care costs and prevent the loss of about 18,000 work-days each year. Each bicycle commuter making the typical seven-mile roundtrip to work could lose 10 pounds per year until reaching his/her optimum weight.

To that end, Mayor Cieslewicz recently appointed a Platinum Bicycling Committee in an effort to make Madison the first city “with real winter weather” to achieve platinum certification from the League of American Bicyclists for being bike friendly. Presently, Davis, Calif., is the only city in the nation with platinum status because 17 to 20 percent of its commuters bicycle. Madison is one of four U.S. cities to earn a gold rating. About 3.5 percent of Madison’s population bikes to work. The national average is a mere one percent.





Native plant, nodding onion: U.S. EPA Visualizing the Great Lakes / Lake Mendota: Jeff Miller, UW-Madison University Communications



**IS IT CLIMATE CHANGE?** Exceptionally low water levels have been observed recently at a large number of lakes in northwestern and north central Wisconsin. As of June 2007, monthly precipitation totals in northwestern Wisconsin had been as much as two inches below normal in all but one of the preceding 12 months. Some lakes in Waushara County and elsewhere in the Central Sands region of the state were also drying up.

Below-normal seven-day average streamflows were recorded in most of the state in August 2007 except in southern and west-central portions of the state. The Palmer Drought Severity Index—a measurement of dryness based on recent precipitation and temperature—showed that northwestern and north-central Wisconsin were in severe to extreme drought during most of the summer, whereas most other parts of the state were in a mild to moderate drought following an unusually moist spring.

## THE RISE AND FALL OF LAKES



Much of this was due to a widespread drought that also affected most of Minnesota, Michigan, Iowa, Indiana and Ohio during the summer of 2007. But many people started wondering why lake water levels had dropped so low. Was climate change perhaps the cause, and if so, what does it mean for the future of Wisconsin's 15,000 lakes, 32,000 miles of perennial streams and other water resources?

**WATER LEVELS GOING DOWN OR UP?** There are few long-term lake level records in Wisconsin, but one of them is for Anvil Lake in Vilas County, near the Michigan border. This record shows there has been a steady long-term decline in the lake's water level since the 1930s, which suggests the cause may be more than a temporary drought. However, not too long ago, in the mid-1990s and again in 2002, high lake water levels were the norm around the state, and many lakeshore properties were flooded.

Another long-term record exists for Shell Lake in Washburn County, which shows—unlike Anvil Lake's record—a generally *upward* trend in water levels since the 1930s. This rise in water levels has been especially pronounced since 1970, despite a large decline caused by dry conditions since 2001. Unlike some other lakes in drought-stricken northern Wisconsin, Shell Lake is nowhere near its recorded lowest levels.

The long-term record for Devil's Lake in Sauk County also shows a general rise in seasonal water levels. And long-term groundwater level data from around the state likewise show an upward trend over the last 30 years.

A 2003 analysis of stream flow and well water records since 1970 throughout the state found a “step increase” in stream flow in 16 of 19 watersheds and a similar jump in water levels at 17 of 20 wells, including some in the northern parts of the state hardest hit by the drought. Is climate change involved in the rise in water levels in most areas, or is it instead behind the drought causing lake levels to decline? The answer: maybe both.

**PROJECTED EFFECTS OF CLIMATE CHANGE** By the end of this century, the projected changes in climate for the Great Lakes region include:

- An increase in average temperatures of 5-20 degrees Fahrenheit in summer and 5-12 degrees in winter. As a result, extreme heat will be more common, and the growing season will be several weeks longer. The length of time the land is snow covered and lakes and rivers are ice covered will be much shorter than it is today.

- Average daily precipitation will increase in winter and spring and decrease in summer and autumn. This means more rain in winter and during the spring planting season, and drier soils and more droughts during the summer growing season and fall harvest.
- The number of severe storms, floods and other extreme events could increase by 50 percent and perhaps even double in frequency.

For water resources in Wisconsin, such changes in climate mean:

- **Major changes in hydrology at the watershed scale.** Precipitation extremes will result in more floods as well as severe droughts that will dry up small streams and lakes. Less ice cover and snow cover will increase winter evaporation and reduce spring runoff.
- **Changes in aquatic species distributions.** For example, white bass will expand northward, coldwater species like trout will disappear from some southern streams, and nonnative species from warmer climates will invade our waters.
- **Reductions in the water quality of lakes, streams, rivers and wetlands.** For example, warmer temperatures will stimulate algal blooms, which can have a variety of adverse ecological, aesthetic, and human and animal health effects.

**HYDROLOGIC EFFECTS** It is difficult to predict the effects of climate change on a particular watershed because its hydrologic cycle involves many interrelated components, including precipitation patterns, water temperature, evaporation rates, groundwater inputs and outputs, and the flow rates of surface waters.

Certain processes in the surface water balance are heavily influenced by rainfall intensity, so the projected increase in heavy rainfall raises several concerns. One is that the rate of percolation of water into the soil is limited. As rainfall intensity increases, soil moisture recharge tends to decrease, and runoff tends to increase.

Another is that evaporation rates will increase with warmer temperatures. In our present climate, rainfall increases during the summer months, which

helps maintain soil moisture and reduces runoff. It also helps keep lake levels from declining. A seasonal shift to less rainfall in summer and more rainfall in winter and spring will affect each of these factors.

For example, less winter ice cover will increase evaporation from surface waters, warmer air temperatures increase evapotranspiration and water consumption by plants, less precipitation in summer will decrease soil moisture. This could cause lake levels to go down.

On the other hand, warmer, wetter winters will increase the recharge of groundwater and improve soil moisture; more carbon dioxide in atmosphere decreases evapotranspiration and increases the water-use efficiency of plants, which enhances both runoff and infiltration to groundwater; baseflow and groundwater levels increase over the long term. This could cause lake levels to go up.

However, a variety of other factors affect lake water levels, including the lake's location, its depth and area, variability in weather patterns, short-term droughts or wet periods, and the amount of water consumed for human uses.

**LAKE HYDROLOGY** Lakes are generally classified as being either a drainage lake or a seepage lake. A drainage lake is surface-water dominated—it gets and releases most of its water via a river or streams. Seepage lakes are generally groundwater dominated—they don't have a surface water source or outlet and rely on groundwater for most of their water. Some seepage lakes receive little or no groundwater and depend primarily on precipitation for their water.

Lakes are also characterized by how water flows through them. These include:

- Recharge lakes, which don't receive but contribute to groundwater and depend on surface-water inflow or precipitation for all their water;
- Flow-through lakes, where water from surface and/or groundwater sources enters from the higher elevation side of the lake and exits on the lower elevation side, and
- Discharge lakes, where most of the water comes from groundwater, and the water level is affected mainly by the level of the water table, rate of evaporation, and the presence or absence of some outlet. Natural springs are a form of discharge lake.

The water level of a lake varies naturally within a range of seasonal highs and lows and occasional extreme highs and lows. This range of natural vari-

Apostle Islands National Lakeshore, Wisconsin: Bobak Ha'Eri



ability is affected not only by precipitation and evaporation, but also by the type of lake and its elevation and position in the landscape.

The water level of groundwater flow-through lakes tends to vary the most—in some cases by as much as 10 feet. Surface water flow-through lakes also tend to have a wide range of water levels as they respond to decreases and increases in surface water inflow due to droughts and heavy rains. Discharge lakes tend to have the most stable water levels because they are constantly being resupplied from groundwater.

Lakes in higher elevations or high in a watershed tend to be seepage lakes. The rise and fall of water levels in these lakes tends to be more affected by precipitation and evaporation, which is why seepage lakes in the upper part of a watershed have a greater response to droughts than drainage lakes.

Lower elevation lakes tend to be more of the flow-through variety and have greater groundwater inputs as well, so they are buffered from short-term dry periods and respond more to long-term changes in groundwater level and recharge rate. As a result, the water level of lakes lower in the landscape are generally more stable.

**IS IT DROUGHT?** As noted earlier, in 2007 much of Wisconsin was in a drought, which was especially severe in the northwestern part of the state. However, the drought in that part of the state has lasted only a few years so far, and we've had longer and much worse droughts in the past. The state as a whole is experiencing nothing near the last extreme drought

we had in the late 1980s that lasted nearly five years. The drought of the infamous “Dust Bowl” years in the 1930s affected Wisconsin for most of that entire decade.

Actually, other than the short record-setting drought that occurred around 1977, Wisconsin has been in an unusually moist period since the mid-1970s. We’ve had many more wet years during the last 30 years than dry ones, including a wet period spanning nearly 10 years from the late 1970s until the late 1980s. Generally, Wisconsin has been much wetter than normal compared to past decades, and this explains the step increase in stream flow and water levels mentioned earlier.

The two areas that haven’t shown a step increase in water levels are in two high elevation areas of the state with lakes of the seepage type that are most vulnerable to drought. Drought also reduces the flow of streams that may supply water to these and other lakes in the area. Lakes in the same area that are lower in elevation and have more groundwater inputs have been less affected by the drought because of higher groundwater levels resulting from three decades of generally wetter-than-normal conditions.

This is illustrated by a long-term groundwater monitoring well the U.S. Geological Survey maintains at a roadside park near Glidden, just south of Ashland at the Lake Superior-Mississippi River basin divide. This well is 1,550 feet above sea level and it doesn’t show the step increase in water levels found elsewhere. The USGS record show the water table there has remained relatively stable since the 1970s, rising about a foot during the wet period that began in the late 1970s and dropping about a foot or so during the extreme drought in the late 1980s.

Like Anvil Lake, three of four lakes at the UW Trout Lake Experiment Station, also located in Vilas County, show a general decline in water levels spanning the last 25 years. In fact, they are lower now than during the period of extreme drought in the 1980s. The water level of the fourth lake shows a slight decline, but it is a drainage lake lower in the watershed, whereas the other three are seepage lakes higher in the watershed.

Moreover, all of these lakes are located in a part the state with forested, sandy soils, where groundwater levels are closely connected to precipitation levels and tend to rise and fall accordingly, which explains why lakes in this area have not shown the step increase in water levels and stream flow seen in other areas.

Anvil Lake and other lakes in higher elevation parts of the state are going to be the first to respond to a change in climate, so they may be sentinel areas responding to climatic signals of a change to generally warmer and drier conditions. Perhaps groundwater-flooded lakes lower in the landscape just haven’t caught up yet.

**THE HUMAN FACTOR** Wet and dry periods will continue, and climate changes will not affect all parts of the state the same way due to variations in local geography and geology. However, climate is not the only driver affecting lake levels and other water resources. The other drivers are all human. Our current regional population of 60 million is expected to continue to grow, leading to more urbanization and sprawl and rising demands on available water supplies. In turn, these changes will likely lead to greater fragmentation of the landscape, disrupting watersheds and runoff patterns.

Along with climate change, these pressures on the environment are expected to worsen some existing water resource problems. Less rainfall in the summer will reduce the recharge of groundwater aquifers, and winter and spring precipitation may run off too quickly to make up the difference. Small streams, especially headwater streams, could run dry in summer. Reduced ice cover during winter and higher evaporation rates during hotter summers are likely to cause a general decline in average lake levels around the state, year-to-year fluctuations notwithstanding. The loss of wetlands coupled with the projected increase in the frequency of heavy rains will create growing problems with flooding, as well as erosion and runoff from agricultural fields and urban areas into streams and lakes. Wisconsin farmers may have to rely more on irrigation to grow crops, which can have significant effects on local water supplies.

**A SAND COUNTY FORECAST** The effects of human water use on lake levels and groundwater levels can be seen in the Central Sands region of the state. The Central Sands is a glacial lake plain that was promoted as a place to grow potatoes and vegetables in the 1950s as part of an economic development strategy. It is now one of the prime potato and vegetable growing areas of the state, and that requires a lot of water for irrigation. As result, the Central Sands watershed has the highest concentration of high-capacity wells in the state—as many as two per square mile.

Waushara County is located in this region and straddles the watershed divide between the Mississippi River and Lake Michigan. Along the divide, the flow of groundwater and surface water splits and goes in opposite directions. Over the last 10 years, the water levels of several lakes located along this divide in northwestern Waushara County have been dropping dramatically—some by as much as 10 feet since the mid-1980s. Located in sandy soil high in the watershed, these are landlocked seepage lakes with no outlet. They are also located in an area with a large number of high-capacity wells.



As water is pumped out of the ground, all wells create what is called a “cone of depression” in the groundwater table. As groundwater seeps in to refill it, this depression can direct the flow of groundwater away from a nearby lake or stream. If the cone is large enough and located near a groundwater divide, it can also reduce the flow of groundwater to one side of the divide or even reverse the flow to the opposite side.

It is unclear how much of the decline in these Waushara County lakes can be attributed to groundwater pumping by nearby high capacity wells and how much is due to the short recent drought in the area. It is likely some combination of the two—and perhaps a foreshadowing of what climate change may bring.

**THINGS WE CAN DO** The key to protecting our lakes and other water resources in a changing climate is to minimize pressures on the environment to reduce its vulnerability to future climate stresses. This means protecting water quality as well as water supplies. This is particularly important for drinking water but also for industries that rely on a steady supply of high-quality water for their operations. Upgrading sewer and septic systems and reducing nonpoint source pollution from urban areas, roads, farmlands and other sources are good examples. We can all increase the reliability of water supplies if we use this vital resource more efficiently.

Particularly valuable in terms of habitat protection would be the rehabilitation of riparian and floodplain forests, which would shade and help keep stream temperatures down and reduce flooding.

Urban and land use planning can reduce sprawl, which not only reduces greenhouse gas emissions from long commutes, but also the amount of paving and stormwater runoff. It also helps reduce destruction and fragmentation of farmland and forests and other natural habitat.

Finally, communities should consider infrastructure improvements and adjustments to water supply systems, floodplain structures and lake shore facilities to anticipate and accommodate drier summer and wetter winter conditions, and a generally much more variable climate in the future.

Storm in Duluth, Minnesota: Gene Clark



**URBANIZED RUNOFF** Let's look at an aspect of climate change at the neighborhood scale. Our present stormwater management systems were not designed to handle the heavy downpours that are expected to increase in intensity and frequency with Wisconsin's changing climate. Managing this additional stormwater is particularly important in urban areas with combined sewer and stormwater systems. Excessive runoff from urban areas can also contribute to flooding and property damage in rural areas.

Urbanization has several adverse effects on local hydrology, including increased flooding, degraded water quality, and decreased base flow in streams and rivers. All three of these result from the increased amount of runoff from the introduction of impervious surfaces and the compaction of pervious surfaces in urban areas. More runoff, coupled with the drainage “improvement” systems built to accommodate it, also increases the *rate* of runoff—which further contributes to flooding and degraded water quality.

## MANAGING MORE STORMWATER

*Based on a presentation by Kenneth Potter, Professor of Civil and Environmental Engineering  
University of Wisconsin-Madison*

Finally, the pumping of groundwater by municipal wells causes a drop in the water table that reduces the base flow of streams and the water level of lakes in the area.

This is illustrated by U.S. Geological Survey stream flow data for Spring Harbor, an urban watershed in Madison, and Garfoot Creek, a small rural watershed just outside of Madison, which are two drainage areas of similar size and hydrology. The USGS data show that runoff amounts from the same precipitation events during 1995 tended to be two to three times more in the urban watershed than in the rural one. It is notable that the base flow is zero in the urban watershed, because the spring for which Spring Harbor was named dried up after the local municipal well was installed.

**CONVENTIONAL PRACTICES** Conventional urban stormwater management practices are based on historical climate. Stormwater management design is commonly based on so-called “design storms,” such as a 10-year 24-hour storm, based on the maximum amount of rainfall recorded in one day in one decade. Such historical climate measures obviously will not be a good indication of future performance if the magnitude of such storms increases.

No one really knows exactly how climate is going to change rainfall patterns, and we won’t actually know how much it has changed until it has been documented with some real measurements a decade or so afterwards. Despite this uncertainty, several approaches are available to address the projected increases in rainfall intensity, especially the large events.

One potentially effective strategy is to design conservatively to hedge against possible increases in storm intensities. Two other potential strategies are to improve the performance of existing systems based on monitoring and modeling, and to introduce a capacity for real-time management.

Presently, four conventional practices for managing stormwater include:

- Conveyance (storm sewers and engineered channels)
- Storage (to control runoff peaks and improve water quality)
- Infiltration (to decrease runoff volumes and increase groundwater recharge)
- Filtration (to improve water quality)

Of these, a combination of storage and infiltration appears to be our best alternative for addressing the potential increase in storm intensities and runoff projected to occur in Wisconsin with future climate change.

**CONSERVATIVE DESIGN** Conservative design may be a hard sell. It means designing bigger ponds and using more developable land because climate change *might* cause rainfall intensity to increase; therefore, a conservative approach requires a logical basis for design development.

One is to regulate to the 100-year event. Madison ordinances, for example, only regulate runoff peaks to the 10-year storm event. The rationale for this is that runoff flows into the lakes, so flooding is not a concern. But that’s not completely true. Part of the runoff from the Madison watershed flows into the Sugar River, and this additional runoff is increasing the 100-year flood plain along the Sugar River. A lot of communities are following Madison’s lead, designing for nothing greater than the 10-year event. It’s important to design for the 100-year event because to do otherwise is putting people into flood plains who weren’t there previously and may not know that they are now.

Many people think that designing to the 10-year event provides a good reduction for the 100-year event. Potter described a simulation he conducted of routing a 100-year flood event through a detention pond designed according to the 10-year event, which demonstrated poor attenuation of peak flow because the storage filled up before maximum attenuation was reached. If the pond fills up before the peak is reached, it provides no benefit towards reducing the peak. This is analogous to the 1993 flood of the Mississippi River. In places where levies breached, hydrographic measures of the river’s flow dropped temporarily. After those flood plain areas filled up, however, the flow basically returned to the same trajectory.

Another strategy is to use regularly updated rainfall statistics. The obvious thing to do is to look at some large events that are bigger than the design storm to ensure that the design can handle or reduce the consequences of such events. This is something to consider, especially if we expect rainfall intensities to increase.

Many stormwater management designs are still based on Technical Publication 40, or TP40, which is 40 to 50 years old now. The TP40 numbers are clearly outdated. The Midwestern Climate Center has produced a set of intensity duration frequency curves that are substantially larger. A 100-year event has gone up by a half-inch or more in most places, yet even that information is more than 10 years old now. If our climate is indeed changing, we need to adjust our intensity to frequency curves more often. However, this could be a challenge for the National Weather Service, because it doesn’t have the budget to redo these frequency curves. Also, because the work takes a long time, the NWS is unlikely to recalculate them anytime soon, so stormwater designers need to pay close attention to what rainfall is doing in their region. We’re fortunate to have the Midwestern Climate Center to assist us.



Lake Mendota: M.F. Rothbart, UW-Madison University Communications

A third strategy is to use the lowest, most conservative pre-development curve numbers that can be justified. A Soil Conservation Service (SCS) hydrology curve number is generally used to predict runoff from the selected storm event (design storm). The selection of a pre-development condition is usually specified in the local ordinance, but designers should investigate whether actual pre-development runoff rates may have been significantly less than that.

Lastly, use infiltration systems aggressively, but do not credit storage towards the peak requirement of the design. Infiltration practices like bioretention facilities or rain gardens are important approaches in a large urban area like Madison because of the large amounts of groundwater being pumped combined with the loss of groundwater recharge due to large areas of impervious surfaces. Infiltration is also important in such areas because greater runoff volume increases flooding, even with stormwater retention. Moderate development in the Lake Mendota watershed, even using everything to control the two- through 100-year peak, would still result in substantially higher peaks on the lake. Because it's a large storage site, Mendota accumulates runoff over a period of weeks and discharges water very slowly because of the downstream flow conditions. It's important to control runoff volume when dealing with sluggish natural systems like the Madison lakes.

**TESTING ASSUMPTIONS** Potter said he had operated under the assumption that infiltration doesn't provide much benefit when it comes to larger events. To test that assumption, he conducted an infiltration simulation using a hypothetical 160-acre development that is half impervious and applied pre- and post-development pervious surface runoff numbers. He designed a retention pond and outlet structure to hold runoff from a

100-year storm at pre-development levels and then ran the simulation a second time using the same 100-year event with 15 percent more rainfall.

The results were startling: the simulation showed that a 15 percent increase in rainfall would overwhelm the runoff control structure, doubling the rate of discharge it was designed to allow. However, when infiltration was added to the design, the rate of runoff remained at target levels or increased somewhat, depending on the type of soil used in the simulation. In the latter case, the target rate was met by increasing the bioretention area for infiltration from seven to nine percent of the total area, or nearly 14.5 acres.

This simulation showed that some benefits toward the peak can be derived from infiltration. Such aggressive infiltration may not be possible everywhere, but infiltration can be useful. However, it is essential when using infiltration that runoff storage requirements are not reduced in stormwater management designs—again, do not credit storage against the peak requirement of the design, and don't take credit towards 100-year event reductions based on infiltration. Those unused credits help keep the design conservative and provide a little excess capacity for handling more intense rainfalls in the future.

**IMPROVING EXISTING SYSTEM PERFORMANCE** The key to improving the performance of our stormwater management systems is to monitor individual runoff storage sites to verify the assumed storage-outflow characteristics and hydrologic parameters. Continuous simulation modeling of the system could also help identify ways to improve system performance.

When we build stormwater management systems, we *think* we know how they behave, but we really don't. The SCS hydrology curve number is just an approximation, and we can't be certain that our models or our characterization of the watershed are accurate, nor that our control and storage structures were constructed properly and are functioning as designed.

Storage performance can be monitored relatively simply with a pressure transducer in the pond and a data logger, and the stage-discharge relationship for the outlet structure can be checked by doing a few current meter measurements. Water-quality performance is especially important with some structures. Our sedimentation models assume quiescent conditions in a storage pond and don't account for resuspension due to turbulence. Unless a sedimentation pond is designed to be quiescent, it's going to be turbulent, so the kind of water-quality treatment down to the eight micron level we expect is likely not occurring.



**REAL-TIME MANAGEMENT** One proposed alternative is to do as reservoir managers now do and coordinate the release of stormwater outflow for flood control. Instead of passive structures, reservoirs employ gates that can modify the amount of passing of water through the system based on real-time observations of the amount of water coming into the reservoir and the amount of rainfall predicted. When the forecast is for an exceptionally large rainfall, they open up the gates to let out enough water in advance to provide the extra storage needed to accommodate a heavy rain.

The question is whether that can be done with an urban retention pond. A simulation using the same data as before—except that some of the runoff is shunted away before reaching the retention pond—didn't significantly reduce the excessive outflow resulting from a 15 percent increase rainfall in a 100-year storm. Since engineers are unlikely to want movable gates on their ponds and performance isn't improved much anyway, this preliminary analysis indicates that real-time management of urban stormwater isn't a feasible nor effective alternative.

However, new stormwater management technologies are being developed for real-time monitoring and better forecasting, and for some systems—water quality treatment systems in particular—we may be able to optimize the performance of existing systems to accommodate better the increases in stormwater runoff that climate change is expected to bring.

Waileye: New York Department of Environmental Conservation



**TWO POSSIBLE FUTURES** The primary piece of evidence that suggests the climate is changing now and is likely to continue to change in the future has to do with atmospheric concentration of carbon dioxide over the last one thousand years. The concentration remained relatively flat—just under 300 parts per million—until the early 1800s, after which it has been increasing steadily to the present level of just under 400 parts per million. At the present rate of increase, it is projected that the carbon dioxide concentration could rise anywhere from 550 to almost 1,000 parts per million, depending on whether human carbon dioxide emissions are controlled or not.

A general upward trend in global air temperature index has accompanied the rise in atmospheric carbon dioxide since 1850. The first 100 years of this record show a lot of variation and no real evidence of a consistent trend. Since the 1960s, however, a comparison of the rise in carbon dioxide and global air temperature shows a clear link between the two, and

## THERMAL SENSITIVITY OF FISHES

*Based on a presentation by Brian Shuter, Research Scientist, Ontario Ministry of Natural Resources; Adjunct Professor of Zoology, University of Toronto*



Great Lakes Fishery Commission

atmospheric scientists tell us more carbon dioxide in the atmosphere means warmer air temperatures.

Natural forces alone cannot account for the increase in global temperature; only when human carbon dioxide emissions are factored into the equation do climate model simulations closely match the observed increase in global temperature.

With this understanding of how human carbon dioxide emissions is driving global warming, we can explore a couple of scenarios of what may occur in the future. One scenario assumes stringent fossil fuel conservation measures are put into place to reduce carbon dioxide emissions—call it the “Prius scenario,” where everybody in the world switches to small fuel-efficient cars. Call the other the “Hummer scenario,” where carbon dioxide emissions are not controlled and everyone continues driving large, low-mileage vehicles.

The Prius scenario still results in almost a doubling of carbon dioxide, after which concentrations level off. The Hummer scenario causes carbon dioxide levels to more than triple in the next 100 years, the consequences of which could be very interesting, to say the least.

**EFFECTS ON LAKES IN OUR REGION** Given these two possible futures, we can make some projections of what might happen to temperature and precipitation in the Great Lakes region. The effects differ greatly between the Hummer and Prius scenarios. For example, by 2100 the summer mean air temperature (June-July-August) is projected to increase roughly five degrees Fahrenheit under the Prius scenario, whereas the Hummer scenario causes average summer temperatures to rise 15-20 degrees, making

our region a very warm place indeed. Precipitation is projected to generally decline during summer and increase in winter under both scenarios until the latter years of the century, when these trends start to reverse under the Prius scenario. Conservative estimates predict a 10 to 20 percent increase in annual rainfall by 2090.

As a rule of thumb, a 10 percent increase in rainfall is needed to maintain existing water levels with each degree rise in temperature. Therefore, for lakes in our region, even the Prius scenario means we can expect lower water levels, longer ice-free periods, an increase in summer surface water temperatures and a longer stratification period.

The projections for future water levels in this region have been controversial, but some consensus is building around the idea that they will drop. Ultimately, how much water levels go down depends on whether our region gets enough additional rainfall to keep up with the rising amount of water lost to evaporation as temperatures increase. Regardless of how little or how much the decline, it means less water for fish.

Small inland lakes in this region generally are ice-covered 90 to 100 days each winter, which keeps a lid on evaporation during that part of the year. This is expected to shrink by 45 to 60 days between 2030 and 2090 as a result of longer ice-free periods and warmer open waters in winter. For the Great Lakes, this means Lake Superior, which normally never has ice-free winters, could be having ice-free winters nearly half the time by 2090. By then, Lake Erie could be ice-free almost every winter.

We are seeing this already. Since about 1960, the duration of winter on Lake Erie—defined as the number of days surface water temperatures are below 39 degrees—is clearly getting much shorter, about 20 days shorter as of 2000. Mid-summer surface water temperatures are showing a steep rise. Similar trends are evident on each of the Great Lakes during the same period.

**EFFECTS ON FRESHWATER FISH** Surface water temperature governs many aspects of the behaviors of fish, and the ways in which many of the fish that live in the Great Lakes react to water temperature is well documented. This knowledge of the thermal preference and performance of different fish species enables us to make reasonable projections about what might happen to different species as temperatures become warmer.

If a fish is put in a tank of water that’s cold at one end and warm at the other, it will swim around until it finds a spot with a temperature it likes. The temperature it chooses is called its preferred temperature. If a fish is held in water at different temperatures and given plenty of food to eat, its rate of



growth increases as the temperature increases until it reaches a peak, after which growth rapidly slows down again. A fish's peak growth rate typically is within a few degrees of its preferred temperature. This is typical of fresh-water fish that live here and elsewhere in Earth's Temperate Zone.

Fishes are characterized by their preferred temperatures and grouped according to whether they prefer low, medium or high water temperatures. These are called the cold-, cool- and warm-water thermal guilds. Members of the cold-water thermal guild like water temperatures under 60 degrees; these include lake trout, salmon, herring and smelt. The cool-water guild likes water in the 60- to 80-degree range and includes walleye, yellow perch, northern pike and crappies. Bass, bullheads, carp and bluegills are members of the warm-water guild and prefer waters 80 degrees and warmer.

Where these fish are found around the country relates to the thermal guild to which they belong. Lake trout, for example, are common in cold Canadian waters, while bass are common in the warmer waters south of Canada. This is how climate controls the distribution of fishes around North America. In other words, fishes that prefer cold temperatures will be found only where the water stays cold, and they will be absent from waters too warm for them to tolerate. The opposite is true for warm-water fishes.

Cold- and warm-water fishes may be found in areas where the temperature is outside their thermal preference, but they are relatively rare because they aren't as able to compete for food as cool-water species that are in their preferred temperature range. As this region heats up, fishes that prefer warmer water will be better able to compete and expand their range northward, and cold-water species will disappear from waters that become too warm for them. Besides lake trout, the losers in this scenario include brook trout, lake whitefish, round whitefish and burbot. Some winners include buffalo, carp, catfish and several species of sunfish.

**LAKE ERIE WALLEYE ANALYSIS** It's a little harder to predict the fate of cool-water species. Walleyes belong to this guild, and without a detailed analysis it isn't apparent where they will be negatively or positively affected.

Lake Erie has a world-class walleye fishery. If the small shallow east end of the lake warms up significantly, the walleye there are not going to be happy. On the other hand, if the small deep eastern end of the lake warms up, the walleye might not be terribly affected because they still have some

deep, cold water there. The turbidity of Lake Erie may also change with warmer temperatures, which means the light environment as well as the thermal environment will change.

An analysis of these factors indicates a 35-degree increase in Lake Erie's surface water temperature and a six-foot drop in its water level would increase walleye habitat in the deep eastern basin by 32 percent, whereas habitat in the shallow western basin will decrease by 26 percent. This would cause Lake Erie's walleye population to decline in the western basin but increase in the eastern end of the lake.

### EFFECTS ON FISH ECOLOGY

Climate change is expected to have four major effects on fish ecology:

- Change in overall fish production in particular aquatic ecosystems.
- Change in relative productivity of individual fish populations in a particular aquatic ecosystem.
- Large-scale shifts in the geographic distribution of species.
- Small-scale shifts in the spatial distribution of members of specific populations.

Consequences for the fisheries of the Great Lakes region include:

- Change in sustainable harvests for all fish populations in an ecosystem.
- Change in the sustainable levels of exploitation that can be directed at fish populations within an ecosystem.
- Change in mixture of species that can be sustainably harvested within a specific region.
- Change in location of profitable fishing grounds.
- Change in sustainable harvest for the population.
- Change in efficiency of fishing gear, leading to change in sustainable levels of fishing effort.



## HOW TO HELP PRESERVE OUR FISHERIES

Shuter outlined six ways of adapting to climate change that could help reduce its effect on the fish populations of Wisconsin and other Great Lakes states:

- **Conserve water**—Increased demand for water for human uses may lead to severe reductions in the amount of suitable habitat available to fish.
- **Redirect fishing effort**—Focus on fish populations whose productivity is improved by climate change.
- **Protect vulnerable fish populations**—Protect those populations whose productivity is diminished by climate change.
- **Reduce the effects of other agents of stress**—Reduce water pollution and inputs of toxic contaminants, limit competition for water between humans and fish, and control access to our waters by invasive species.
- **Actively accelerate the northward shift of warm-water species, and/or**
- **Actively protect cold-water species from competition with warm-water species.**

It is clear that climate change is already underway. Some future change is unavoidable; however, *if limited*, the effects of this change on aquatic environments can be evaluated and plans and efforts made to address them. Any delay in controlling human greenhouse gas emissions will accelerate both the rate and magnitude of future change. This will make planning and mitigation difficult—and perhaps impossible.

Lake Superior, Wisconsin: Karen Rodriguez



**FOUR CLIMATE SCENARIOS** This presentation reviewed the results of a study of hydrological effects of climate change in the Great Lakes region conducted by the National Oceanic & Atmospheric Administration's Great Lakes Environmental Research Laboratory.

To establish a climate baseline, researchers collected daily precipitation and maximum- minimum air temperatures data for 1948-99 from 1,800 meteorological stations around the Great Lakes, and temperature, wind speed, humidity and cloud cover over the lakes from 40 stations.

Using these data to represent present climate conditions, three different general circulation models were used to simulate four future climate scenarios: "warmer and dry," "hot and dry," "warmer and wet," and "hot and wet" This enabled the scientists to determine the effects of the full range of projected maximum/minimum air temperatures and high/low precipitation amounts for hydrological analysis. Evaporation and precipitation are the two most important factors controlling Great Lakes water levels.

## THE ONCE-GREAT LAKES?

Based on a presentation by Thomas E. Croley II, Research Hydrologist  
Great Lakes Environmental Research Laboratory, NOAA

All four climate change scenarios projected a general increase in temperature across the region, with areas in southern latitudes tending to become much warmer than northern ones. The “hot and wet” scenario produced the largest temperature rise. The “warmer and wet” scenario produced the largest increase in precipitation.

Around Lake Michigan, for example, all four climate scenarios show seasonal temperatures over land will be warmer throughout the year than in the past. The “hot and dry” scenario produced the greatest increase in winter and spring temperatures, while the “warmer and wet” scenario resulted in the warmest summer and fall temperatures.

The seasonal temperature cycle remained similar to the historic climate in all scenarios. Possible changes in seasonal precipitation patterns were less clear, with the “dry” scenarios alternating between higher and lower than the present climate. Precipitation in both of the “wet” scenarios increased in all seasons except summer.

**EFFECTS ON WATERSHED HYDROLOGY** The four climate change scenarios then were run through a watershed hydrology model and applied to all of the 121 watersheds that contribute water to the Great Lakes. Although each scenario gave different estimates of the change in precipitation over each lake basin, the increase in temperatures in all four scenarios caused a significant reduction in snowpack, particularly in the northern latitudes. All four future climate scenarios indicated soil moisture would also be less than in the past.

Across the Michigan watershed, all of the scenarios predicted water from snow will be less than half of what it has been during winter and spring. Under the “wet” scenarios, the annual cycle of precipitation peaks about the same time as in the past, at least on a monthly time scale, while in the “dry” scenarios it seems to peak about a month earlier, which is true for soil moisture levels as well. In all scenarios, soil moisture in the basin increases more during the winter than in the past, reflecting less snowpack storage, and it is less during the remainder of the year than today.

Increased air temperature also significantly increases average annual evapotranspiration throughout the Great Lakes basin in all climate change scenarios. Interestingly, the “warmer and wet” scenario shows the most evapotranspiration, particularly in the southern part of the basin. While this result may seem odd, this scenario also delivers the largest increase in precipitation of all the climate change scenarios, so more water is available for evapotranspiration.

Increased evapotranspiration and decreased snowpack will result in less runoff. Runoff under the “warmer and wet” scenario appears to be most similar to the baseline. Runoff decreases the most in the “hot and dry” scenario, and decreases the least under “warmer and wet.”

Evapotranspiration on the Michigan watershed increases under all scenarios except in June in the “dry” scenarios and July in the “hot” scenarios. The evapotranspiration peak occurs in May and June for the “hot and wet” scenario, probably because water availability is less limiting under that scenario. Runoff is greater in the winter in all scenarios because of the reduction in snowpack, and it is less during the rest of the year, which reflects the patterns in snow and soil moisture.

**EFFECTS ON LAKE THERMODYNAMICS** The four climate change scenarios were then run through lake thermodynamic models. Water and air temperature and wind speed are key determinants of Great Lakes evaporation rates.

The “wet” scenarios generally indicate less cloud cover, which transferred more heat into the lakes than the “dry” scenarios. The “dry” scenarios predict slightly higher wind speeds than today, while both “wet” scenarios produce about the same amount of wind. The seasonal cycle of cloud cover and wind is about the same as today—cloudier and windier in winter than in summer.

Similar to predicted over-land air temperatures, average air temperatures over the lakes are warmer than today in all four climate scenarios, with the warmest temperatures occurring under the “hot and wet” scenario. All four scenarios show average humidity will be higher throughout the seasonal cycle than in the past.

The “hot and dry” scenario produced the highest humidity, which may seem counterintuitive until the seasonal cycle is examined. Temperatures and humidity under the “hot and dry” scenario are higher in the winter and spring, but the peak occurs a month earlier than today. Consequently, humidity in the “hot and dry” scenario is highest during the time of year when humidity is generally low anyway, so it’s not going to significantly affect evaporation.

For Lake Michigan, all four scenarios omit lake ice entirely, and the amount of heat stored in the lake is higher in all seasons than in the past. Both “hot” scenarios transferred more heat into the lake, despite the “hot and dry” scenario’s larger amount of cloud cover.

All four scenarios showed an increase in heat absorption and water temperature in each of the Great Lakes, with the largest water temperature

increases occurring in the northernmost lakes. The largest increase occurs under the “hot and dry” scenario, the least under the “warmer and dry” scenario. The deep lakes are predicted to have surface temperatures that frequently stay above 39 degrees Fahrenheit throughout the year. This will prevent buoyancy-driven turnovers of the water column, resulting in changes in bottom chemistry, oxygen depletion, and the release of nutrients and metals released from lake sediments. It will also practically eliminate ice cover from the lakes.

Under all of the climate change scenarios, the increase in heat storage alone is sufficient to cause increased evaporation from all of the Great Lakes. The most evaporation occurs under the “hot and wet” scenario; the least under the “warmer and dry” scenario. In the case of Lake Michigan, the rise in surface temperature and increased evaporation are spread throughout the seasonal cycle, with the largest increases in both temperature and evaporation occurring during the summer.

**EFFECTS ON GREAT LAKES BASIN WATER SUPPLIES** The combination of precipitation, runoff and lake evaporation gives us the net basin water supply to each lake. All of the changed-climate scenarios indicate net basin supplies will generally be less than the historic annual average for all of the Great Lakes.

The “warmer and wet” scenario most closely resembles the historic baseline of net basin supply, meaning it would cause the least amount of change as compared to today. The greatest losses in net basin water supplies occur under the “hot and dry” scenario. In between are the “warmer and dry” and “hot and wet” scenarios, which have about the same net effect.

On a seasonal basis, net basin supplies will be less from May through November in all of the future climate scenarios. Only the “warmer and wet” scenario shows a higher net basin supply during the winter and part of the spring than in the past.

Projected higher air temperatures lead to greater over-land evapotranspiration and lower runoff to the Great Lakes. Runoff peaks earlier, since the snowpack is reduced and the snow season is greatly shortened. This also causes in a reduction in available soil moisture throughout the basin.

Under all scenarios, water temperatures climb and peak earlier; resident heat in the deep lakes increases throughout the year. Mixing of the water column diminishes. Ice formation is greatly reduced on the deep Great Lakes. All of these cause evaporation to increase.

As a result, average net basin supplies drop most where precipitation increases are modest (the dry scenarios), but they decline under each of the climate-change scenarios in all northern and mid-latitude basins. Net basin supplies are essentially the same—maybe a little higher—for the two southern lakes only under the “warmer and wet” scenario.

In sum, these findings suggest a warming climate can be expected to bring a decline in the water levels of the Great Lakes, particularly the big three upper lakes. The extent of that decline largely depends on whether precipitation increases significantly and whether the rise in regional temperatures can be minimized through large, meaningful reductions in global greenhouse gas emissions.





Native plant, awned graceful sedge: EPA Visualizing the Great Lakes / Lake Superior, Duluth Harbor: Minnesota Sea Grant



**LOW LAKE WATER LEVELS** In September 2007, Lake Superior broke an 81-year-old record low for the month when it dropped more than two feet below its historic average September water level. In December 2007, Lake Michigan nearly broke its December record low set in 1964 when its water level dropped 27 inches below the monthly average. All along both Wisconsin coasts, the drop in water levels left lakefront property far from the water's edge. Ships were forced to carry less cargo to avoid grounding in shallow channels, docks were rendered useless, boats left high and dry, and shallow bays dried up entirely. The Bad River Band of Lake Superior Chippewa canceled its wild rice harvest for the first time in history because low water levels had dramatically reduced the rice crop in their coastal wetlands.

Some suspect that climate change is the culprit behind the recent low water levels in the upper Great Lakes and that this may be the harbinger of a long-term continuing decline. In fact, models of regional climate change that

## UNKNOWN ON OUR COAST

*Based on a presentation by J. Philip Keillor, Coastal Engineering Advisory Services Specialist (Retired), University of Wisconsin Sea Grant Institute*



assume less rainfall and greater evaporation from much warmer temperatures predict a drop in average lake levels of one foot to more than four feet in less than 50 years, while models assuming greater rainfall with a lesser increase in temperatures indicate average lake water levels could rise instead by as much as a foot by the end of the century.

The immediate cause of the recent low water levels is a two-year drought affecting the basins of both lakes that may or may not be related to climate change. Another contributing factor may be the erosion of the Lake Michigan-Huron outlet at the St. Clair River northeast of Detroit that has expanded and/or deepened sections of the river by six to nearly 22 feet, greatly increasing the rate of outflow and causing an estimated one-foot long-term drop in the average level of both lakes since the early 1960s.

**DOWN AND UP AGAIN** The water level of Lake Superior has fluctuated by as much as four feet during the last century, while Lake Michigan's has varied by as much as six feet. And the rate of rise and decline in lake water levels can be relatively rapid.

For example, Lake Michigan's water level declined nearly five feet in three and half years on two occasions during the 20th century, and once it went down as much as four feet in just over two years. Twice during the last century the lake's water level dropped as much as three feet in just one year. Conversely, Lake Michigan's water level rose more than three feet in 18 months or less on three occasions during the 20th century, and it went up more than five feet in just over eight years during the 1965-73 period.

During the last century, the water levels of both Lakes Michigan and Superior have been at times much lower than any recorded in recent years. In the distant past, Great Lakes water levels have been both much higher and much lower than anything seen since Europeans came to this continent 400 years ago.

The 140-year-long record of historic Great Lakes water levels is simply too short to make a confident prediction of future lake-level fluctuations in a changed climate, particularly if global warming induces more extreme fluctuations in temperature and precipitation than projected or experienced to date. Coupled with projected changes in the long-term average water levels of the lakes, those extremes could also cause greater extremes in the seasonal high and low water levels on the Great Lakes.

Because Great Lakes coastal cities were built for the relatively narrow range of lake levels seen over the last two centuries, this creates a multi-billion-dollar dilemma for private and public owners of coastal facilities, including water utilities, power plants, ports, marinas, and business and residential property.

The questions surrounding future Great Lakes water levels resemble those for the projected rise in sea level in one respect: Our coastal communities and infrastructure were developed for a range of water levels that no longer seems valid, and coastal property managers need to evaluate the sensitivity of such places to water levels beyond the ranges for which they were designed.

**CLIMATE CHANGE PROJECTIONS** Climate model projections do not predict the future but provide plausible scenarios of what our climate may look like in the future. These scenarios can then be used to understand the range of risks this presents that can be used to identify our options for dealing with them effectively.

Climate model projections for Wisconsin indicate that by 2030 average summer temperatures will rise five to eight degrees Fahrenheit in summer and two to three degrees in winter. Precipitation may remain about the same as today, or it may be as much as 10 percent less in summer and 25 percent more in winter.

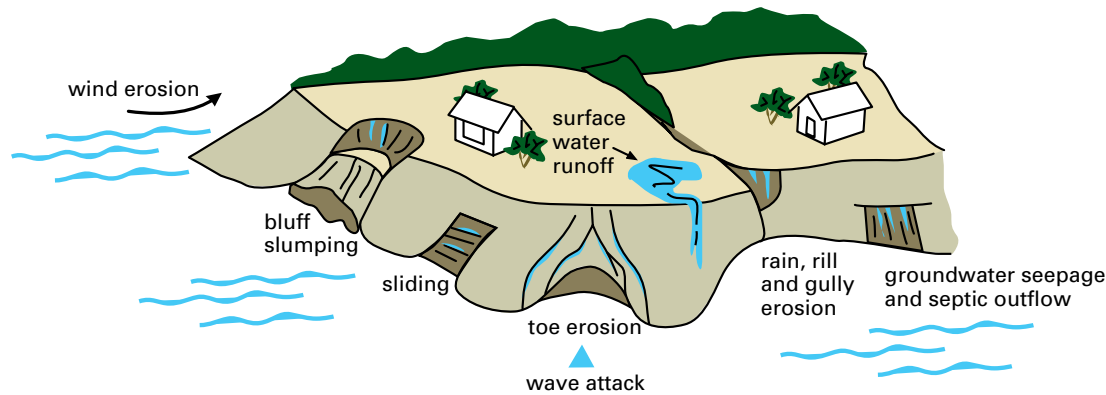
Severe or extreme storms are likely to become more frequent, increasing 50 to 100 percent by 2095. As a result of global warming, the atmosphere can hold more moisture, increasing the amount available for precipitation. Together, these changes are expected to result in greater and more frequent extreme precipitation events.

Wisconsin has already seen an increase in such events. Since 1970, the proportion of *heavy* (top five percentile) and *very heavy* (top one percentile) precipitation events has increased in the western Great Lakes and Upper Midwest. In southeastern Wisconsin, three of the four rainfall events that matched or exceeded the hypothetical "once-in-500-years" standard during the 20th century have occurred since 1970—in August 1986, June 1996 and June 1997. (The fourth was in August 1924.)

Wisconsin may also be in for some climate surprises from shifts in storm tracks due to the changes in atmospheric circulation occurring in most seasons in both hemispheres. This is similar to the way an El Niño event in the Pacific Ocean affects storm tracks crossing North America and the Great Lakes. Such changes in storm tracks can cause abrupt changes in climate. One possibility is a persistent shift in storm tracks either into or outside the Great Lakes Basin.

For the Great Lakes, warming air temperatures are also expected to result in warmer water temperatures that could eventually lead to the disappearance of lake ice in winter. On Lake Superior, the coldest Great Lake, surface water temperatures are rising at a faster rate than air temperatures over the

## Causes and Effects of Coastal Erosion



lake. This is the result of a “positive feedback” mechanism similar to that occurring in the Arctic Ocean, in which warmer air temperatures reduce the amount of ice cover, leaving more open water to absorb heat from the sun, which melts more ice cover and creates more open water that absorbs yet more heat. At the current rate of ice cover loss, Lake Superior could be ice-free in a typical winter within 40 years.

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**EFFECTS ON THE COAST** Some potential effects of these projected changes in climate on our coastal areas include more erosion of coastal slopes, added stress on coastal structures from extreme events, and disruption of human activities due to swings in Great Lakes water levels beyond their historic range of high and low water levels.

Warmer, wetter winters with shallow frost and more frequent, longer freeze-thaw periods will increase surface erosion, causing shallow slides and more failures of slopes subject to deep slips, along with the possibility of massive failures during complete thaws. This would cause even more erosion in coastal areas where soil creep exists, such as along the Lake Superior shore.

More extreme precipitation events in winters without frozen soil will cause similar problems and contribute to massive slope failures due to higher groundwater levels.

A lack of ice cover on the Great Lakes would mean no protective ice ridges or ice shelves along the shore and expose erodible slopes to a greater amount of wave attack at their base, which can cause shallow as well as massive slope failures.

Dryer soils in summer and fall, combined with more frequent extreme precipitation events, would also result in greater surface erosion and shallow slides and increase erosion in areas where soil creep is a problem.

Extreme precipitation events are also likely to cause catastrophic failures of coastal slopes, washouts of coastal roads and storm sewers, record-setting stormwater discharges, flooding and other damage to harbor infrastructure, and failures of old bulkheads, dock walls and seawalls.

Lakebed erosion can be a significant and continuing problem wherever and whenever waves, currents, and abrasive sand and gravel move across soft clay sediments. In other Great Lakes states, lakebed erosion at rates of one to six inches per year has deepened lakebeds by one to five feet within a decade.

## RESPONDING TO THE RISKS

Four strategies for coping with coastal erosion are to:

- Moderate erosion.
- Adapt to natural coastal processes.
- Restore natural shorelines.
- Armor the shore (shore protection).

The risks to coastal property posed by erosion can be moderated by controlling surface runoff, intercepting groundwater beneath the property, and monitoring development in the area that may route more groundwater and surface water through the property. Other ways to moderate erosion are to slow wind erosion by planting vegetation and to improve existing slope toe protection structures.

Adaptation to natural coastal processes can be accomplished by relocating houses threatened by coastal erosion or flooding, adopting greater setback distances for new coastal construction and building houses that are easily relocated.

Natural shorelines can be restored by creating and preserving coastal environmental corridors, and by improving or restoring natural shore protection features, such as beaches, dunes, wetlands, nearshore shoals and islands.

Armoring the shore is the strategy of last resort. One reason is that shore protection structures may have adverse effects on the property they are designed to protect and on neighboring property as well. Another is that lakebed erosion can undermine and destroy virtually every type of shore protection structure known.

For more detailed information about coastal processes and managing the risks, Keillor recommended *Living on the Coast: Protecting Investments in*

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*Shore Property on the Great Lakes*, a 2003 publication of the University of Wisconsin Sea Grant Institute and the U.S. Army Corps of Engineers-Detroit District.

Another potentially useful reference is *Coastal Processes Manual: How to Estimate the Conditions of Risk to Coastal Property from Extreme Lake Levels, Storms and Erosion in the Great Lakes Basin*, a UW Sea Grant coastal engineering guide published in 1998.

Copies of both may be downloaded free of charge from the “Water Levels/Erosion” section of the UW-Madison Aquatic Sciences Center’s “Publications Store” Web site at <http://aqua.wisc.edu/publications>.

**MINIMIZING THE RISKS** Ultimately, the level of risk to Great Lakes coastal property and infrastructure posed by changes in Great Lakes water levels and extreme precipitation events caused by climate change can best be minimized and managed by minimizing the rate and extent of global climate change in the decades ahead. Failure to reduce global greenhouse gas emissions, particularly carbon dioxide, could have unforeseen and potentially catastrophic effects on the Great Lakes as well as the rest of the world.

How fast and how much our climate and Great Lakes water levels change will largely determine our ability to adapt—and how costly it will be.

## SPEAKER BIOGRAPHIES



“Climate Change and Potential Impacts on Wisconsin’s Lakes, Streams and Groundwater,” August 8, 2007, Ashland, Wisconsin

### TIM ASPLUND

Tim Asplund is a limnologist with the Wisconsin Department of Natural Resources’ Lakes and Wetlands Section, with lake management responsibilities statewide. He received master’s degrees in Water Resources Management and Oceanography & Limnology in 1993 from the

University of Wisconsin–Madison, where he first became interested in global climate change impacts on lakes. His thesis focused on the variability of oxygen depletion rates in lakes under the ice, examining the implications of a warmer climate. He has worked for the DNR for 14 years, both as a researcher and a water resources management specialist. His current areas of expertise include groundwater and lake interactions, shallow lake ecology, recreational impacts on lakes, and statewide lake assessment.



“Great Lakes Climate Change Hydrologic Impact Assessment,” March 13, 2007, Green Bay, Wisconsin

### THOMAS E. CROLEY II

Thomas E. Croley II has served as a research hydrologist at the NOAA Great Lakes Environmental Research Laboratory for over 25 years. Prior to that, he was an associate professor and research engineer at the

University of Iowa’s Institute of Hydraulic Research. He received a B.C.E. and M.S. in civil engineering from Ohio State University and a Ph.D. in civil engineering (stochastic hydrology) from Colorado State University. His research interests are in hydrology, large basin runoff modeling, water resources forecasting, operational hydrology and lake thermodynamics modeling. He currently serves as associate editor of the *Journal of Hydrologic Engineering*, and he is a U.S. board member of the International Coordinating Committee on Great Lakes Hydraulic and Hydrologic Data.



“Climate Change Coming to the Coasts of Wisconsin: How It May Affect Coastal Communities and Property Owners,” August 15, 2007, Mequon, Wisconsin

**J. PHILIP KEILLOR**

Philip Keillor is a former coastal engineering specialist with the University of Wisconsin Sea Grant Institute. Throughout his career, he has helped Wisconsin’s governments, coastal residents and communities cope with natural hazards, harbor dock and dredging problems, and other coastal issues. In 2005 and 2006, Keillor worked on a NOAA-funded contract with the Association of State Floodplain managers to apply its “No Adverse Impacts” floodplain management practice to addressing of coastal hazards on all U.S. coasts. He also led a Great Lakes-wide effort to develop new guidance on shore protection for coastal property owners. Funded by the U.S. Army Corps of Engineers, the resulting 2003 publication, *Living on the Coast: Protecting Investments in Shore Property on the Great Lakes*, was the Corps’ first publication on the subject in a quarter century. In 2004, the Sea Grant Extension Assembly awarded Keillor the “William Z. Wick Visionary Career Leadership Award” for his work on coastal hazards.



“Climate Change: A Great Lakes Regional Perspective,” June 7 and 11, 2007, Superior and Milwaukee, Wisconsin

**JOHN J. MAGNUSON**

John Magnuson is an emeritus professor of zoology and former director of the Center for Limnology at the University of Wisconsin–Madison. His research interests are in long-term regional ecology, the effects of climate change on inland waters, biodiversity and invasions, and fish and fisheries ecology. Magnuson played a lead role in the lakes and streams portions of the 1995 and 2001 assessments by the Intergovernmental Panel on Climate Change, as well as the 2003 Union of Concerned Scientist’s “Confronting Climate Change in the Great Lakes Region.” He has served on the projects committee and the science advisory panel for the Wisconsin Nature Conservancy, and on the science advisory boards of the International Joint Commission on Water Quality and the Great Lakes Fisheries Commission. He is the recipient of the “Award of Excellence” from the American Fisheries Society and the “Lifetime Achievement Award” from the American Society of Limnology and Oceanography.



“Climate Change and Public Health Concerns,” September 12, 2007, Madison, Wisconsin

**JONATHAN PATZ**

Jonathan Patz, M.D., MPH, is an associate professor of environmental studies and population health sciences at the University of Wisconsin–Madison, where he directs a university-wide initiative on global environmental health. He is a senior fellow of the Center for World Affairs and the Global Economy (WAGE), an adjunct associate professor at the Johns Hopkins Bloomberg School of Public Health, and an affiliate scientist of the National Center for Atmospheric Research (NCAR). He has served as a co-chair for the health sector expert panel of the U.S. National Assessment on Climate Variability and Change, convening lead author for the United Nations Millennium Ecosystem Assessment, and lead author on several United Nations Intergovernmental Panels on Climate Change. He is a coeditor for the journal *Ecohealth: Conservation Medicine and Ecosystem Sustainability*, and he has written over 60 peer-reviewed papers addressing the health effects of global environmental change.



“Adaptive Strategies to Climate Change for Stormwater Management,” March 13, 2007, Green Bay, Wisconsin

**KENNETH POTTER**

Ken Potter is a professor of civil and environmental engineering at the University of Wisconsin–Madison. He received a B.S. in geology from Louisiana State University in 1968 and a Ph.D. in Geography and Environmental Engineering from the Johns Hopkins University in 1976. His teaching and research interests are in hydrology and water resources, including estimations of hydrological risk, especially flood risk; stormwater modeling, management and design; assessment and mitigation of human impacts on aquatic systems; and restoration of aquatic systems. He has been a member of several National Research Council committees and is currently chair of the Committee on Integrated Observations for Hydrologic and Related Sciences and a member of the Committee on New Orleans Regional Hurricane Protection Projects. He is a Fellow of the American Geophysical Union and the American Association for the Advancement of Science.



“Effects of Climate Change on the Fish and Fisheries of the Great Lakes Basin,” September 24, 2007, Manitowoc, Wisconsin

**BRIAN SHUTER**

Brian Shuter received his doctorate in aquatic ecology at the University of Toronto in 1975. He is currently a research scientist with the Ontario Ministry of Natural Resources and an adjunct professor at the University of Toronto. His research has focused on the role of climate in shaping the distributions and life histories of freshwater fish. Over the last decade, he has helped review potential impacts of climate change on freshwater fish for the federal government of Canada, the American Fisheries Society, the International Joint Commission, the Ecological Society of America and the Union of Concerned Scientists.

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“Global Warming Is Unequivocal,” April 23, 2007, Madison, Wisconsin  
Keynote Presentation

**KEVIN TRENBERTH**

Kevin E. Trenberth is a senior scientist and head of the Climate Analysis Section at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. He has authored more than 400 publications in the area of climate, and he is among the most highly cited researchers in all of geophysics. His research interests are in global-scale climate dynamics—the observations, processes and modeling of climate changes from interannual to centennial time scales—and he has particular expertise in El Niño, the hydrological and energy cycles, and hurricanes and climate change. He was a lead author of the 1995 and 2001 Intergovernmental Panel on Climate Change (IPCC) Scientific Assessment of Climate Change. For the first volume of the most recent IPCC report, released in February 2007, Trenberth is the coordinating lead author of chapter three, which discusses observations of surface and atmospheric climate change.



## **FOR MORE INFORMATION**

### **Climate Change in the Great Lakes Region: Starting a Public Discussion**

*<http://www.seagrant.wisc.edu/ClimateChange>*

### **Intergovernmental Panel on Climate Change**

*<http://www.ipcc.ch>*

### **National Oceanic & Atmospheric Administration Climate Research**

*<http://www.oar.noaa.gov/climate>*

### **Union of Concerned Scientists**

Confronting Climate Change in the Great Lakes Region

*<http://www.ucsusa.org/greatlakes/glchallengereport.html>*

Climate Change in Wisconsin

*<http://www.ucsusa.org/greatlakes/glregionwis.html>*

### **U.S. Global Change Research Program**

The Potential Consequences of Climate Variability and Change: Midwest Overview

*<http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewmidwest.htm>*

### **UW-Madison Center for Climatic Research**

*<http://ccr.meteor.wisc.edu>*

### **UW-Extension Wisconsin Climate Information**

*<http://www.uwex.edu/sco/state.html>*

### **Wisconsin State Climatology Office**

*<http://www.aos.wisc.edu/~sco>*

See also *The Discovery of Rapid Climate Change* by Spencer Weart, director,  
Center for History of Physics, American Institute of Physics

*<http://www.physicstoday.org/vol-56/iss-8/p30.html>*