CHICAGO CLIMATE ACTION PLAN

CLIMATE CHANGE AND CHICAGO

PROJECTIONS AND POTENTIAL IMPACTS

EXECUTIVE SUMMARY 09-18-2008

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Acknowledgements

We acknowledge the role of the City of Chicago, especially Suzanne Malek McKenna, Karen Hobbs, Brendan Daley, Mike Johnson, Antonia Ornelas and Stefanie Salonis in the Department of the Environment, for their leadership in making this assessment happen.

We also thank the Global Philanthropy Partnership, in particular Julia Parzen and Adele Simmons, for their leadership and organization of the assessment.

Finally, we thank the Chicago Climate Task Force and the Research Advisory Committee for their advice, input, and encouragement.

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Executive Summary

The city of Chicago, with a population of just under three million people, is the third largest city in the United States. Its economy is primarily based on manufacture and transportation of goods, although in recent years increasing revenue is also being generated by real estate and tourism. As the financial, industrial, and cultural capital of the Midwest, Chicago is responsible for roughly 34.6 million metric tons of heat-trapping or "greenhouse" gases, in CO_2-equivalent terms. Adding in the six surrounding counties in the Chicago area increases this to about 103 million metric tons per year. This region accounts for nearly half the total emissions of the state of Illinois[1], with emissions greater than the state totals of more than 30 individual states.

Chicago has the humid continental climate typical of the Midwest, moderated by its location just west of Lake Michigan. Its weather conditions range from snowy, icy, and windy winters to hot, humid and sweltering summers. Chicago's climate is not merely familiar to its inhabitants; it is the basis for their way of life. When the first snow can be expected, how long winter will last, which flowers to plant in spring, what outdoor activities can be enjoyed in summer – all of these are aspects of life in Chicago that take for granted a stable and predictable climate.

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[1] Chicago's proportion of Illinois emissions may seem lower than expected, as Chicago represents such a large proportion of Illinois' population. This is due to the fact that Illinois emissions include those from the electricity it exports (approximately 28%); that airport emissions in Chicago from O'Hare and Midway, which total approximately eight million metric tons per year, are not included in the city's inventory; and finally that downstate emissions from agriculture and and industrial natural gas use are significant.

QUANTIFYING UNCERTAINTY

Certainty estimates provided here are based on expert opinion.

In general, temperature-related projections tend to be more certain while precipitation projections are less so. The sign of trends (whether negative, positive, or inconclusive) is usually more certain, while the absolute magnitude of changes projected to occur by a certain time period are less so.

Following the convention of the Intergovernmental Panel on Climate Change, we use the following indications of probability of occurrence of future projections:

Virtually certain > 99%

Extremely likely > 95%

Very likely > 90%

Likely > 66%

More likely than not > 50%

Unlikely < 33%

Chicago's climate is already changing, however. Temperatures have risen by 2.6°F since 1980. Fifteen of the last twenty years have seen above-average annual temperatures. Many of the defining characteristics of the city are being altered, including:

- Winters warming by almost 4°F since 1980
- Decreases in winter ice coverage on Lake Michigan and smaller lakes in the area
- A longer growing season, with flowering of trees and plants occurring a week earlier than during the previous century
- Several major heat waves, particularly those in 1995 and 1999
- Shifts in the water cycle, with less snow in winter, earlier spring melt
- A doubling in the frequency of heavy rainfall events over the last hundred years

It is extremely likely that global temperatures and temperatures over Chicago are expected to warm further over coming decades, as human emissions of heat-trapping gases continue. However, the extent of future warming and the impacts that will result from that warming depend strongly on the magnitude of future emissions. For that reason, in estimating potential future impacts from climate change, we focus on two alternative futures.

In the "higher" emission scenario, Chicago and the rest of the world continues to depend on fossil fuels as their primary energy source, and atmospheric carbon dioxide levels rise from their present-day levels of 385 parts per million (ppm) to almost 1000 ppm by the end of the century. Under the "lower" emission scenario, a focus on sustainability and conservation results in atmospheric carbon dioxide levels rising to about 550 ppm by the end of the century. It is important to note, however, that the lower scenario does not represent a lower boundary on possible futures. It is very probable that timely and aggressive action to reduce emissions over the next few decades, such as that laid out in the Chicago Climate Action Plan, could limit climate change to below that projected under the "lower" emissions scenario examined here.

Given a specific scenario, determining the climate change that would result is still uncertain due to limitations in scientific understanding of the climate system and how it will respond to increasing emissions from human activities. In this report, we address the scientific source of uncertainty by using simulations form three different climate models. The climate models used here cover the accepted range of how the climate system is likely to respond. These three models were selected based on several criteria, including their ability to represent the past climate, particularly over the United States and the Midwest, and the availability of simulations for the higher and lower emission scenarios used here.

Since global climate models cannot resolve individual cities, statistical techniques and long-term historical observed climate records were also used in the analyses to scale down the results and make them more specific to the Chicago region. This scaling uses advanced statistical and scientific techniques to ensure the climate model simulations are able to reproduce observed climate averages and day-to-day variability over Chicago. Then, historical observations, climate model simulations, and the latest statistical methods were combined to evaluate past trends and potential future changes in Chicago's climate over the coming century. The impacts of these changes on Chicago's public health system, water supply, ecosystems, infrastructure, and other key sectors were then assessed.

Beginning with **temperature**, our analysis shows that Chicago could see substantial increases in annual and seasonal temperatures and extreme heat events, particularly under the higher emissions scenario. Specifically:

- Seasonal and annual temperatures are extremely likely to increase over the coming century. Over the next few decades, changes on the order of 1-1.5^{o}F are likely. By the end of the century, under lower emissions, temperature could increase by 3-4^{o}F; under higher emissions, 7-8^{o}F under the higher emissions scenario, with the greatest increases (up to 10^{o}F) during summer.
- Year-to-year variability is more likely than not to increase, resulting in an increased frequency of very hot summers over time, rather than a gradual increase in mean summer temperatures.
- The seasonal range of day-to-day temperatures is also more likely than not to change, with the difference between the warmer and colder days of winter becoming smaller, while the difference between hotter and cooler days in spring and summer becomes greater.
- The number of very hot days (over 90^{o}F) is very likely to increase as well. By the end of the century, very hot days are projected to increase from the present-day level of about 15 days per year to 5 weeks under the lower emissions scenario and 8 weeks under the higher. Proportionally, an even larger percentage increase is projected in

extremely hot days (over 100^{o}F), with more than 30 of these days projected to occur each year by end-of-century under the higher emissions scenario.

- The frequency, duration, and intensity of heat waves in Chicago are likely to increase substantially, and the heat-wave “season” (time during the year when extreme heat can be expected) extended. Heat waves with similar characteristics to the 1995 event (to which almost 700 deaths are attributed) are projected to occur twice a decade by mid-century. By the end of the century under lower emissions they could be as frequent as every other year, while under higher emissions there could be several such heat waves each summer.
- The difference between “apparent temperature” (how hot it actually feels due to both humidity and temperature) and actual air temperature during heat waves is likely to increase as the climate warms. In other words, hot days could feel even hotter due to increased humidity, creating more severe heat stress conditions in the future than suggested by projected increases in air temperature alone.
- The length of the frost-free or “growing” season is very likely to continue to expand, with the date of last (spring) frost projected to move earlier in the year by about 30 days under the higher scenario and 20 days under the lower scenario by the end of the century.
- Significant decreases in the number of frost days per year and the annual frost depth are also likely, with larger changes towards the end of the century and under the higher vs. the lower emissions scenario.
- The frequency and intensity of extreme cold days and cold spells are likely to decline considerably during this century. The temperature of the coldest day of the year is projected to warm by 4 to 6^{o}F through this century, while the frequency of extremely cold days (the coldest 5 to 10% of all days) is expected to decrease by approximately 30% under the lower emissions scenario up to 70% under the higher scenario.

The projected increases in extreme temperatures over the coming century, with longer, more frequent, and more intense summer heat waves, could have a number of adverse impacts on **human health and welfare**. Extreme temperatures and resulting decreases in air quality can lead to increases in both morbidity (illnesses) as well as mortality (deaths), although warmer winters would also reduce cold-related mortality. In particular:

- As temperatures warm and atmospheric circulation patterns change, oppressive summer weather patterns could arrive in Chicago earlier in the year and last longer, causing air quality to decrease and further affecting respiratory illnesses and disease.
- Both average annual morbidity (illness) and mortality (death) rates for circulatory and respiratory diseases affected by heat could increase, with greater increases projected under the higher as compared to the lower emissions scenario.
- Currently, just under 100 deaths in Chicago are attributed to extreme heat each year. An “analog city” analysis, which transposes the weather conditions from the European Heat Wave of 2003 (responsible for 40,000 deaths across Europe) to the city of Chicago, estimates that if a similar heat wave were to occur over Chicago, given its present-day infrastructure, demographics, and emergency preparedness, more than ten times the annual average number of heat-related deaths would occur in just a few weeks. However, this number also has the potential to be significantly reduced by adaptation strategies implemented by the city as well as by future changes in demographics and infrastructure.
- Climate projections indicate that it is likely that a 2003-type heat wave could occur in Chicago by mid-century and extremely likely that it would occur before the end of the century. Between mid- and end-of-century there could be as many as five such events under lower emissions scenario. Under the higher emissions scenario, similar events could occur as frequently as every other year.
- Cold-related morbidity and mortality is more likely than not to decrease as winter temperatures warm. However, most winter mortality is due to the transmission of infectious agents as people are confined indoors for longer periods of time, rather than being caused by individual extreme cold events. For this reason it is difficult to quantify both the relationships between cold weather and health issues as well as how current rates of cold-related illnesses and deaths might be altered by future climate change.

As temperatures warm and atmospheric circulation patterns change, bringing oppressive summer weather patterns to Chicago earlier in the year and making them last longer, **air quality** is also expected to decrease. The primary way that air quality is measured is through ground-level ozone. Although ozone is not produced directly from human activities, combustion of fossil fuels – particularly in the transportation sector – produce high levels of "precursor" pollutants that react in the atmosphere to form ozone. Ozone production tends to increase as temperatures warm. Specifically:

- Based on regional climate and air quality simulations driven by temperature changes projected to occur under the lower emissions scenario, average daily summer ozone levels in the city could increase by about 10% under the lower emission scenario and about 25% under the higher emission scenario due to climate change alone (assuming human-related emissions of precursor pollutants remain at current levels).
- Ozone variability is projected to almost double under the higher emissions scenario but decrease by 20-30% under the lower scenario, implying that a smaller temperature increase could lead to weaker variations in pollution levels and hence fewer occurrences of extreme ozone days, while a greater temperature increase could raise both ozone background levels as well as the frequency of ozone exceedance days.
- An alternative method for calculating changes in future surface ozone levels, based on statistical correlations between historical observations and large-scale atmospheric circulation patterns, yielded similar results when applied using the same temperature projections as the model simulations above – increases of about 10% to about 25% under lower and higher emission scenarios, respectively. However, additional calculations using the higher end of the possible temperature range indicate that, under higher emissions, summer ozone levels could increase by as much as 50% by end-of-century.
- These analyses assume ozone precursor emissions are maintained at present-day levels. Clearly, reducing local emissions of nitrogen oxides, volatile organic compounds, and other pollutants that react to form ground-level ozone is a key adaptation measure to reduce ozone levels even while temperatures continue to warm.

Shifting climate zones can also affect the frequency of **vector-borne and water-borne disease** outbreaks. Vector-borne pathogens are those disease agents for which the route of transmission from one host to another involves an insect or other arthropod, such as a tick or a mite. While many vector-borne illnesses are associated with the tropics, the Chicago region is not immune. In

Illinois, the two most common vector-borne diseases currently are West Nile Virus (WNV) illness, carried by mosquitoes, and Lyme disease, carried by ticks.

- Vector-borne disease in the Chicago area is currently a low-level but on-going health concern that has increased over recent decades. Since 2002, the counties of Cook and DuPage have reported almost 1100 cases of human illness from WNV. The bacteria that causes Lyme disease, carried by the deer tick, has emerged in the region recently.
- Warmer weather and changes in precipitation patterns could be more likely than not to accelerate current trends of increased risk of exposure to vector-borne diseases in the region, especially West Nile virus. Warmer summers mean a longer mosquito season and higher temperatures that allow them to develop faster. Heat waves have further intensified WNV transmission throughout the Midwest. In general, past outbreaks have been associated with very warm temperatures (2002) and very dry conditions (2005).
- Waterborne disease outbreaks from all causes in the U.S. are distinctly seasonal, clustered in key watersheds, and associated with heavy precipitation. Heavy runoff after severe rainfall can also contaminate recreational waters and increase the risk of human illness through higher bacterial counts. Heavy precipitation events have already increased in frequency over the last century and are likely to continue to increase in the future, raising concern about the potential for future waterborne disease outbreaks

As climate changes, changes in **precipitation patterns** are also expected over the Chicago region. These changes range from shifts in seasonal distributions to changing proportions of rain vs. snow. In particular:

- Increases in winter and spring precipitation are likely, with projected increases of about 10% by mid-century and 20-30% by the end of the century under both higher and lower emissions.
- There is as likely as not to be little change in summer and fall precipitation, although increasing temperatures are likely to increase summer evaporation rates, reducing soil moisture.
- The intensity of heavy precipitation events is likely to continue to increase, although at different rates depending on what threshold is used to define “heavy” precipitation.

- The implications of increases in heavy rainfall events for flood risk are difficult to assess, as flood events depend on a number of factors including the exact location of the rainfall, the condition of the ground, and infrastructure. However, rainfall events of 2.5 inches or more in 24 hours have been associated with Chicago flooding in the past, and the frequency of these events is projected to increase in the future. This suggests that adaptation may be required to counteract a possible enhancement in flooding and storm water.
- Although winter temperatures are very likely to continue to warm, it is more likely than not that only a slight decrease in snowfall occurs under the higher emissions scenario and little change under the lower emissions scenario. This is because the effect of warmer temperatures may be counteracted by increased winter precipitation. Warmer temperatures are likely to reduce snow cover on the ground, however, with a projected loss of up to 30 days of snow cover under higher emissions and half that under lower emissions by end-of-century.

Changes in rainfall, snow, and other precipitation patterns across the region will also affect the region's **hydrology**. Hydrological variables include evapotranspiration, which measures how much water is transferred from the ground and through plants back into the atmosphere; soil water storage, representing the amount of water available in the soil for plants to grow; the amount of water flowing in rivers; and lake levels, particularly for Lake Michigan, Chicago's primary water supply. In particular:

- Over much of the century, evapotranspiration is likely to increase in all seasons, with greater increases under the higher emissions scenario as compared to the lower. There is the possibility of a slight decrease in the near term in winter, however, due to slight increase in soil frost.
- Runoff is also likely to increase as the century progresses, especially under the higher scenario.
- Small annual increases are more likely than not in soil moisture, with small decreases possible in summer months due to the warmer temperatures.
- A slight increase in peak flow amounts in the Illinois River is likely under the lower emissions scenario over the coming century, but a major increase under the higher emissions scenario, increasing the risk of flooding and associated damages

- Little change in Lake Michigan levels is more likely than not under the lower emissions scenario, as the effect of increasing temperatures and evaporation is balanced by more precipitation during winter and spring. However, under the higher emissions scenario the effect of warmer temperatures and decreased ice cover may dominate, resulting in an average decrease in lake levels of 1.5 feet by the end of the century.
- Warmer temperatures and changing rainfall patterns are likely to alter the risk of beach contamination. Chicago beach closures tend to be correlated with heavy rainfall events, warmer lake temperatures, and lake stage levels. With more frequent and intense heavy rainfall events, warmer lake waters, and lower water levels being projected over the coming century, more frequent contamination events may be expected.

Although the natural environment surrounding Chicago has already been modified by housing, development, and agriculture, climate change is also affecting **local ecosystems**, including plant growing conditions and animal habitats in the region. The impacts of climate change on typical tree and plant species, wildlife, and pests in the Chicago area are expected to continue over the coming century. Many species currently native to the Chicago region are likely to be driven further north as temperatures warm, while more heat-tolerant species move into the region. Even species that are not directly affected by changing temperatures could be indirectly affected if their food sources shift out of the area. In general, future effects on plants, animals and ecosystems will depend on both the emission scenario followed as well as on land use management choices that could assist in adaptation and minimize climate impacts. In particular:

- By mid- to late century, according to the Chicago region's USDA Plant Hardiness Zone designation, growing conditions could resemble those in southern Illinois under the lower emission scenario or those in the Tennessee River Valley under higher emissions.
- Suitable habitats for some plant species are likely to shift northward or otherwise decline in importance. Others now found further to the south will become more important. For example, the area of habitats for important tree species such white oak, maples, and northern red oak could decline substantially. Less common hardwoods, such as aspens and paper birch would become rare, and some conifer species may disappear altogether. Southern oaks and other tree species now

uncommon or absent could appear if seeds are able to reach the region and establish themselves, or if humans enable their establishment.

- Animal populations associated with existing habitats will decline or increase depending on resource availability and their ability to adapt to or move with changing climates. An increasingly developed landscape will be a substantial barrier to animal migration, so active ecosystem management and "assisted migration" may be necessary to facilitate species movements into and through the region.
- There is the potential for about 45 bird species to lose at least half of their suitable habitat in the Chicago region by the end of the century under lower emissions, while about 25 species would gain at least twice their suitable habitat. Under higher emissions, more than 50 species would lose at least half of their suitable habitat, while about 35 species would gain
- The impacts of plant and animal pathogens could increase with higher temperatures and longer growing seasons in both non-agricultural and agricultural ecosystems.
- The region's highly productive farms are expected to be impacted negatively by increases in springtime flood risk, increasing development pressures, pests, pathogens, and warmer and drier summers. Longer growing seasons could enhance productivity, however, while newer drought-resistance crop varieties and irrigation might offset some moisture stress.
- In the future, lake surface temperatures are likely to warm earlier in the spring than they do now, reach higher summer temperatures, and cool more slowly in the fall. However, the effects of these changes on aquatic ecosystems are complicated. Although primary production of phytoplankton, the base of the lake food chain, may begin earlier in the year, more rapid and stronger stratification (formation of isolated water layers in the lake) in summer may limit the availability of nutrients and reduce the size of the phytoplankton crop. Such a reduction would have negative effects on zooplankton and fish that depend on the phytoplankton for their food energy, as well as reducing the amount of oxygen available to bottom-dwelling bacteria, plants and animals.
- Warmer water temperatures may also affect fish, favoring warm water species over current cold water types. Climate-driven changes in the

structure of the Lake Michigan ecosystem may be especially important near shore, the areas most visible and important to Chicago.

- Warmer temperatures and changes in nutrient cycling may stimulate the growth of filamentous algae, which is both an aesthetic problem and a possible promoter of pathogens.
- Winter ice cover, which tends to shield the shoreline and near-shore lake bottom from the disturbing effects of storms, may be reduced significantly. Together with projected increases in winter and spring precipitation and lake levels, this could increase shoreline erosion and decrease near-shore water quality.

Changes in climate will also affect Chicago's **infrastructure** and **economy**. Potential impacts include the effects of heavy rainfall events and extreme temperatures on roads, bridges, highways, and rail systems; the potential for damages to buildings and other infrastructure from increased flooding, with subsequent impacts on insurance coverage and rates; changes in frost depth and air temperatures that require alterations in current building codes; and finally, shifts in the timing and amount of seasonal energy demand for both residential and commercial heating and cooling. Specifically,

- As temperatures and extreme precipitation rise, so will most economic costs. These costs can only be partly offset by savings due to warmer winters. For city government alone, the projected costs of adaptation are almost four times higher under the higher emissions scenario than they are under the lower emissions scenario.
- Over the coming century, as temperatures warm, electricity demand for cooling is likely to increase while energy demand for heating is likely to decrease. These changes imply a potentially large shift in the energy market in Chicago, with a decreasing demand for natural gas in the winter and increased demand for electricity during the summer months.
- More frequent, severe, and longer heat wave events could also increase the likelihood of electricity shortages, leading to brown-outs or even black-outs as have been experienced in St. Louis, New York City, and many California cities in recent years.
- Additional costs more likely than not to be incurred by the city under a changing climate include higher costs associated with road repairs and maintenance; landscaping; increased frequency of fire, police, and emergency response calls; use of non-local hospitals during extreme

heat events; water treatment and harbor dredging; property insurance; and reduced summer tourism.

The climate in the Chicago area has already begun to change. Temperatures have risen by several degrees, causing trees and plants to flower earlier in the spring, frosts to occur later in the fall, and the amount of winter ice on Lake Michigan and inland lakes to decrease. These changes are not simply natural variations in climate. Most of them are likely being caused by human emissions of heat-trapping gases.

This report outlines the even greater changes in climate that may occur over the coming century. These are only a few examples of the many possible ways that global climate change could impact Chicago's population, water resources, natural ecosystems, and infrastructure over the coming century.

In general, these findings confirm earlier projections of climate change impacts on the Midwest and Great Lakes region[2,3]. However, the results of this analysis reveal for the first time the overwhelming importance of the emissions choices made by Chicago and the rest of the world, and how these will determine the magnitude of the climate change impacts that Chicago is likely to experience over the coming century.

Under a higher emissions pathway, by the end of the century Chicago summers could feel like those of Mobile, AL, with day-to-day summer heat index values (that combine the effects of temperature and humidity) averaging 105°F. In contrast, under the lower emissions scenario examined here, Chicago summers could feel more like Atlanta, GA, with an average summer heat index of 94°F. Deliberate choices to reduce emissions of carbon dioxide and other heat-trapping gases could limit the amount of change even further.

What does the future hold? Will the people of Chicago and the rest of the world actively engage to reduce their emissions, or will we continue our dependence on fossil fuels? Scientists can only offer advice, not certainty, regarding what the future will look like. The decisions made by individuals, city governments, states,

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[2] Kling, G., K. Hayhoe, L. Johnson, R. Lindroth, J. Magnuson, S. Moser, S. Polasky, S. Robinson, B. Shuter, M. Wander, M. Wilson, D. Wuebbles and D. Zak, 2003. Confronting Climate Change in the Great Lakes: Impacts on our Communities and Ecosystems. Boston, MA: Ecological Society of America and the Union of Concerned Scientists. Available online at: www.ucsusa.org/greatlakes

[3] Great Lakes Regional Assessment Group, 2000. Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change. Ann Arbor, Michigan: University of Michigan. Available online at: www.usgcrp.gov/usgcrp/nacc/greatlakes.htm

and nations are what will set the pathway for emissions over the coming century and ultimately determine how climate change will affect the City of Chicago.

In order to avoid the most serious consequences of human-induced climate change, Chicago has committed to reduce its heat-trapping gas emissions to 25% below 1990 levels by 2020, and 80% below 1990 levels by 2050 – a target that would, if all of the cities and countries together achieve this reduction, limit future climate change to *less* than that projected under the lower emissions scenario examined here. Regardless of the overall future, every individual and every business can contribute to their own personal “insurance” against the most damaging of future impacts by reducing their personal emissions.

At the same time, however, it is essential to realize that we will not be able to eliminate future climate change entirely. We still must prepare to adapt to some degree of change. As described in the companion adaptation report to this climate impacts assessment, the City is therefore also proposing to:

- Prepare for heat waves through implementing a heat watch warning system already proven to save lives; evaluating power vulnerability and the potential risks of heat stress among key populations most at risk in Chicago; developing collaborative action plans to manage these risks; and updating current heat stress regulations for future change.
- Reduce summer energy use through a home weatherization program, a green infrastructure program (including landscaping, reflective roofing, reflective and permeable pavement, and rooftop garden requirements), and a cooling initiative to spur innovation.
- Improve air quality through reducing ground-level ozone precursor emissions of pollutants from vehicles and other sources.
- Prepare for increases in the frequency of heavy rainfall events and flood risk through: development of a Chicago watershed plan that takes into account projected long-term changes; collaboration between municipal and city agencies to determine the potential to use landscapes to manage stormwater; and finally, use Green Urban Design strategies to capture rain where it falls.
- Implement measures to protect Lake Michigan shoreline from erosion
- Adapt Chicago’s trees and plants to a changing climate through a new planting plan recommending plants that remove pollutants, help manage heat, absorb stormwater, and can tolerate expected climate changes.

Although some future changes are unavoidable, because of past emissions, the worst of the projected changes do not have to happen if we act to reduce our emissions now. Decisions made by individuals, cities, states, and nations are what will determine whether we follow a higher or lower emissions pathway into the future.Through reducing our energy use and preparing for future change, we can help protect our communities, economy, and ecosystems.

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Katharine Hayhoe is a research associate professor in the Department of Geosciences at Texas Tech University, and CEO of ATMOS Research & Consulting. Katharine's research examines the impacts of human activities on the global environment, using global and regional climate models of the earth-atmosphere system. Much of her work is driven by the need to communicate the urgency of climate change and its impacts at the regional scale to those who will be most impacted by them. To that end, she has previously led regional climate assessments for the state of California and for the U.S. Northeast, to determine the potential impacts of climate change on human health, the economy, agriculture, water resources, and other important aspects of the environment we live in, and is currently serving as Lead Author on the Unified Synthesis Product, an assessment of climate change impacts on the United States. Her studies, published in journals including Science, Proceedings of the National Academy of Sciences, and Climatic Change, have resulted in her work being cited by the UN IPCC Fourth Assessment Report, presented before Congress, and highlighted by state and federal agencies in support of actions to reduce greenhouse gas emissions from human activities. Katharine served as lead author on this report, as well as contributing to the climate, water, and health analyses.

Donald Wuebbles is the Director of the School of Earth, Society, and Environment at the University of Illinois. He is also a Professor in the Department of Atmospheric Sciences as well as in the Department of Electrical and Computer Engineering. Dr. Wuebbles was Head of the Department of Atmospheric Sciences from 1994 until 2006 before accepting the new position. He earned his B.S. (1970) and M.S. (1972) degrees in Electrical Engineering from the University of Illinois. He received his Ph.D. in Atmospheric Sciences from the University of California at Davis in 1983. He is the author of over 380 scientific articles, most of which relate to atmospheric chemistry and global climate change as affected by both human activities and natural phenomena. His research emphasizes the development and use of mathematical models of the atmosphere to study the chemical and physical processes that determine atmospheric structure, aimed primarily towards improving our understanding of the impacts that man-made and natural trace gases may be having on the Earth's climate and on tropospheric and stratospheric chemistry. He has been a lead author on a number of national and international assessments related to these issues. Dr. Wuebbles was elected a member of the International Ozone Commission in 2000, and in 2005 received the Stratospheric Ozone Protection Award from the U.S. Environmental Protection Agency. Don served as lead author on this report, as well as contributing to the climate and air quality analyses.

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Keith Cherkauer works to integrate field based observations, remote sensing products and hydrology models to address questions and concerns related to environmental change and to further our understanding of land-atmosphere interactions and the hydrologic cycle. His recent research has included the impact of snow and soil frost on the surface water and energy balance in the upper Mississippi River basin, as well as an investigation of the applicability of aircraft- and satellite-based thermal remote sensing to monitoring stream temperatures. He is also studying the significance of seasonal soil frost in the United States and Canada and how that may change with regional climate, as well as trying to understand the relative importance of land use and land cover change, and climate change in controlling water supplies in the Great Lakes region. For this report, he led the hydrological modeling to estimate the projected impact of climate change on the region's water resources.

Jessica Hellmann is an Assistant Professor in the Department of Biological Sciences at the University of Notre Dame in Notre Dame, Indiana. Her research concerns the responses of biodiversity to climate change and the interaction of climate change with habitat loss and invasive species. She currently studies native oak-grasslands of western North America to understand constraints on geographic range shifts in insects and plants. Dr. Hellmann earned her Ph.D. from Stanford University and held postdoctoral fellowships at Stanford and the University of British Columbia. She sits on an advisory panel for endangered invertebrates in British Columbia, is an associate editor for the journal, Evolutionary Applications, and was recently awarded a career enhancement award from the Woodrow Wilson Foundation. Her research is funded by the Department of Energy, the California Energy Board, World Wildlife Fund Canada, and the National Science Foundation.

Tracey Holloway is an assistant professor at the University of Wisconsin--Madison in the Nelson Institute for Environmental Studies working with the Center for Sustainability and the Global Environment (SAGE). Holloway's research examines air pollution chemistry and transport at regional and global scales, and connections between climate change, energy use, and air pollution. Holloway earned her Ph.D. in Atmospheric and Oceanic Sciences from Princeton University, working at the NOAA Geophysical Fluid Dynamics Laboratory (GFDL). As a graduate fellow through the Princeton Environmental Institute, she also completed a certificate in Science, Technology, and Environmental Policy from the Woodrow Wilson School of Public and International Affairs. Her work has been supported by grants from the Department of Defense, NASA, and the EPA. She and her students at Wisconsin provide the ozone projections base on statistical analysis for this report.

Louis Iverson is a research landscape ecologist who received his BS and PhD degrees from the University of North Dakota, then studied as a Fulbright-Hayes Scholar at the University of York, England, primarily in restoration ecology. He then worked as a forest ecologist for the Illinois Natural History Survey and the University of Illinois and began his Forest Service career in 1993. He has been studying the potential impacts of climate change since that time, along with landscape projects ranging from restoring oak communities with prescribed fire to modeling the emerald ash borer movements to modeling coastline vulnerability to tsunami damage. He is also Adjunct Professor at the Ohio State University, past vice-president of the International Association for Landscape Ecology and a past president of the US Chapter of IALE.

Stephen Matthews is an ecologist working part time for the USDA Forest Service. Also, he is a PhD candidate at The Ohio State University. His research is focused on modeling avian and tree species distribution patterns. In addition to his interests in research at broad spatial scales, his PhD research addresses the habitat requirements and behavior of birds during migratory stopover in urban environments.

Norman Miller is a Staff Hydrometeorologist at Berkeley National Laboratory, Associate Director of the Berkeley Water Center, and is an Adjunct Professor in the UC Berkeley Geography Department and the Department of Hydrology and Water Resources at the University of Arizona-Tucson. He leads the Regional Climate System Modeling and Impacts Group at Berkeley Lab. His research includes analyzing atmosphere and land surface processes across space and time scales, evaluating and quantifying the range of climate change impacts, and advancing new computational techniques for climate simulations. He is a contributing author of the Intergovernmental Panel for Climate Change Assessment Reports, the Southwestern U.S. National Assessment, and the California Assessment Reports.

Knute Nadelhoffer is a Professor in the Department of Ecology and Evolutionary Biology at the University of Michigan and Director of the UM Biological Station near Pellston, Michigan. His research focuses understanding of ecosystem structure and function, including nutrient cycling, water use, species composition, plant growth and organic matter decomposition. He conducts research projects in temperate forests and arctic tundra where he combines field experiments and modeling studies to predict how ecosystems respond to climate change, air pollution and physical disturbances. He has published over 100 research articles and book chapters. He was a Fulbright Research Fellow at the Norwegian Institute of Water Research and the Norwegian Institute of Forest Research (1996-97) where he synthesized studies of North American and European studies of nitrogen deposition affects on forests. He served as Director of the Ecosystem Studies Program at the National Science Foundation (NSF) in 2002-2003 and as President of the Association of Ecosystem Research Centers in 2006. He has authored or co-authored over 100 articles and book chapters on ecosystems and biogeochemistry.

Anantha Prasad received his bachelor's degree in Electrical Engineering from Bangalore University in India and a master's degree in Environmental Resource Analysis from Miami University in Oxford, Ohio. He started his career working as an Aeronautical Engineer. As a research intern he was involved in a USAID project estimating carbon emissions from Sub-Saharan Africa at the Environmental Sciences Division of Oak Ridge National Laboratory in Tennessee. As a Research Associate at Dept. of Forestry, University of Illinois, his main focus was on the GIS aspects of modeling and mapping changes in tropical forest biomass. He has also worked with the 1990 Tropical Forest Resource Assessment project at the Food and Agricultural Organization in Rome, Italy as a GIS consultant. After joining the Forest Service, he has concentrated his efforts in GIS, statistical modeling, computational requirements and technology transfer of research projects – particularly the U.S. Global Change Program study, modelling and mapping changes in tree habitat distribution due to climate change in the eastern United States. He has also been active in training people in GIS technology and in technology transfer using web-based resources.

Matt Peters is a GIS Technician at the U.S. Forest Service Northern Research Station. He is a graduate of Ohio University where he earned a B.S. in GIS Analysis. He then began working for the Forest Service in May of 2006 and is involved in most of Louis Iverson's recent research. He has been extensively examining the destruction left by the emerald ash borer within a section Toledo and helping to develop a colonization model for Ohio and Michigan. Matt has also produced many of the maps that appear in the new Tree and Bird Atlas website for the Eastern United States. His current research involves an assessment of forest site quality based on an Integrated Moisture Index and Forest Inventory and Analysis data for Ohio.

Marilyn Ruiz is Clinical Assistant Professor of Geographic Information Systems and Spatial Analysis in the Department of Pathobiology at the University of Illinois, Urbana-Champaign. Her research interests are in the ecology of infectious disease and in environmental factors related to disease transmission. Her recent work involves an assessment of the spatial patterns of West Nile virus (WNV) in the Chicago area, in which she is considering social and environmental characteristics of neighborhoods that contribute to high rates of mosquito infection from WNV and subsequent human illness. She is also working with the State of Illinois to analyze the epidemiology of Chronic Wasting Disease in deer in northern Illinois and has contributed to research on the decline of Cricket frogs in Illinois, the spread of Lyme of disease the Midwest, and a comparison of St. Louis Encephalitis and West Nile virus in Cook County. In this report, she contributed to the section on vector-borne disease. Dr. Ruiz received her PhD in Geography from the University of Florida in 1995, and was on the faculty at Florida State University and the Staff at the Army Corps of Engineers Construction Engineering Research Laboratory before joining the University of Illinois in 2001.

Scott Sheridan is an associate professor of climatology in the Department of Geography at Kent State University. His research interests include synoptic climatology, climate change and climate variability, and heat impacts upon human health. Dr. Sheridan received his Ph.D. in Climatology from the University of Delaware. He has received funding from the US Environmental Protection Agency, National Science Foundation, and California Air Resources Board. In addition, he has served as field editor of the International Journal of Biometeorology, and will become editor-in-chief in 2008. In this report, he contributed to the future estimates of heat mortality under different climate change scenarios.

Steve Vavrus is an Associate Scientist in the Center for Climatic Research at the University of Wisconsin-Madison. His research interests are in global and polar climate change, cloud and cryospheric processes, extreme events, and paleoclimate. Dr. Vavrus received his Ph.D. from the University of Wisconsin-Madison in atmospheric science with a minor in geography. He is the chair of the American Meteorological Society's Polar Meteorology and Oceanography Committee and an associate editor for the Journal of Applied Meteorology and Climatology. Dr. Vavrus recently received a research fellowship at the National Center for Atmospheric Research to study the role of clouds and abrupt climate change in the Arctic. In this report he contributed to the sections on extreme heat and cold waves and heavy precipitation events.

Lewis Ziska is a Plant Physiologist with the USDA's Agricultural Research Service. He is senior author on more than 50 peer-reviewed publications documenting the impact of rising carbon dioxide and global climate change on weed biology in managed and natural eco-systems. After graduating from the University of California, Davis, he began his career as a Smithsonian fellow, then took up residence as the Project Leader for global climate change at the International Rice Research Institute in the Philippines before joining USDA. At present he is investigating the role of rising carbon dioxide and changing climate on weed-crop competition, invasive/noxious weeds, weed management, and weeds and public health. Dr. Ziska's research has appeared in National Geographic, The New York Times, USA Today, The Washington Post, Newsweek, U.S. News and World Report and CNN Headline News. He was recently featured in the HBO documentary, "Too Hot Not to Handle".