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Description of document:	Nebraska Emergency Management Agency (NEMA) records concerning the impact of climate change or extreme weather on emergency management in Nebraska 2014-2019
Requested date:	03-January-2020
Release date:	27-January-2020
Posted date:	06-October-2024
Source of document:	Nebraska Emergency Management Agency Public Records Request 2433 NW 24th Street Lincoln NE 68524 Internet Contact Page

NEBRASKA
EMERGENCY MANAGEMENT AGENCY

Good Life. Great Strength.

Pete Ricketts, Governor

January 27, 2020

RE: Public Record Request

This letter is in response to your correspondence dated January 3, 2020, and received by us on January 24, 2020, in which you requested certain records from us under the Nebraska Public Records Statute, Neb. Rev. Stat. §§ 84-712 through 84-712.09 (2014, Cum. Supp. 2016). Specifically, you requested, *"a copy of any agency studies, reports or memos concerning the impact or potential impact of climate change and/or extreme weather on emergency management in the State."*

Nebraska Emergency Management Agency has not conducted any agency studies, reports or memos like those you describe; However, I do serve on the Nebraska Climate Assessment Response Committee and have included all electronic files related to that position.

You may also want to reach out to the Nebraska State Climate Office at the University of Nebraska-Lincoln. They may have published articles and research on climate change that is pertinent to your research.

With the delivery of this email containing this letter and the records you requested, we now consider this record request filled.

Sincerely,

Bryan Tuma
Assistant Director

Daryl Bohac, Director

Nebraska Emergency Management Agency

2433 NW. 24th Street
Lincoln, Nebraska 68524

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Understanding and Assessing Climate Change: Implications for Nebraska

EXECUTIVE SUMMARY

Globally, we face significant economic, social, and environmental risks as we confront the challenges associated with climate change. The body of scientific evidence confirms with a high degree of certainty that human activities in the form of increased concentrations of greenhouse gases (GHGs) since the beginning of the Industrial Revolution, changes in land use, and other factors are the primary cause for the warming that the planet has experienced, especially in recent decades.

Is there a debate within the scientific community with regard to observed changes in climate and human activities as the principal causal factor? The short answer here is "no", at least certainly among climate scientists—that is, those scientists who have actual expertise in the study of climate and climate change. For more than a decade, there has been broad and overwhelming consensus within the climate science community that the human-induced effects on climate change are both very real and very large. The debate today is restricted to precisely how these changes will play out and what actions we will need to take to adapt to and mitigate the effects of these changes.

The magnitude and rapidity of the projected changes in climate are unprecedented. The implications of these changes for the health of our planet, and the legacy we will leave to our children, our grandchildren and future generations are of vital concern. Therefore, it is imperative that we develop strategies now to adapt to the multitude of changes we are experiencing and will continue to experience in our climate. This process of adaptation must begin at the local level, where these changes are being observed and their impacts felt. However, global agreements on the reduction of GHG emissions are a critical part of the solution in terms of mitigating as much future warming as possible.

The goal of the UNL climate change report was to inform policy makers, natural resource managers and the public about i) the state of the science on climate change, ii) current projections for ongoing changes over the twenty-first century, iii) current and potential future impacts and iv) the management and policy implications of these changes. Hopefully, this report will lead to a higher degree of awareness and the initiation of timely and appropriate strategic actions that enable Nebraskans to prepare for and adapt to current and future changes in our climate.

The Earth's Climate System

Changes to the components of the earth's climate system are caused by changes in forcings, or external factors, that may be either positive (lead to warming) or negative (lead to cooling). Climate forcings can be classified as natural or anthropogenic, that is human-induced. Examples of natural forcings include solar variability and volcanic eruptions, while anthropogenic forcings include GHG emissions, aerosol production, and land-use changes. Changes in natural forcings have always occurred and continue today, having produced climate change and variability throughout the earth's history; only recently have anthropogenic forcings become large enough to significantly affect the climate system.

Nearly all the energy driving the climate system comes from the sun. Although solar output varies over time and has led to climate changes during the earth's geologic history, changes in solar radiation cannot account for the warming observed over the past 30 years, during which accurate measurements of solar output have been made. In the absence of solar forcing, arguably the largest climate forcing is due to changes in atmospheric composition, particularly of GHGs and aerosols. Global climate models cannot reproduce the recent observed warming without including anthropogenic forcings (particularly GHG emissions).

Evidence that human activities influence the global climate system continues to accumulate because of an increased understanding of the climate system and its response to natural and anthropogenic factors, more and better observations, and improved climate models. In fact, in their latest assessment report, the Intergovernmental Panel on Climate Change (IPCC) now states with 95% confidence that human influence is the main cause of the observed warming in the atmosphere and oceans and other indicators of climate change and that continued emissions of GHGs will cause further warming and changes in these components of the climate system. Before the large-scale use of fossil fuels for energy (starting during the Industrial Revolution), the concentrations of the major GHGs were remarkably constant during human history. Since then, the concentration of these gases has risen – slowly at first, then more rapidly since the middle of the twentieth century. Furthermore, scientists can say with very high confidence that the rate of increase of these gases is unprecedented in the last 22,000 years.

Evidence for a Changing Climate

Multiple lines of evidence show that the earth's climate has changed on global, regional and local scales. Scientists from around the world have collected this evidence from weather stations, satellites, buoys, and other observational networks. When taken together, the evidence clearly shows that our planet is warming. However, temperature change represents only one aspect of a changing climate. Changes in rainfall, increased melting of snow and ice, rising sea levels, and increasing sea surface temperatures are only a few of the key indicators of a changing climate.

Projected Changes in Nebraska's Climate

Projected changes in temperature for Nebraska range from 8° to 9° F by the last quarter of the twenty-first century (2071-2099). This range is based on our current understanding of the climate system. The range of temperature projections emphasizes the fact that the largest uncertainty in projecting climate change beyond the next few decades is the level of heat-trapping gas emissions that will continue to be emitted into the atmosphere.

The number of high temperature stress days over 100°F is projected to increase substantially in Nebraska and the Great Plains region. By mid-century (2041-2070), this increase for Nebraska would equate to experiencing typical summer temperatures equivalent to those experienced during the 2012 drought and heat wave. The number of warm nights, defined as the number of nights with the minimum temperature remaining above 80°F for the southern Plains and above 60°F for the northern Plains, is expected to increase dramatically. For Nebraska, the number of warm nights is expected to increase by an additional 25 to 40 nights.

With the projected increase in global and regional temperatures, there has been an increase in heat wave events occurring around the world. This can be demonstrated by the ratio of maximum temperature records being broken in comparison to the number of minimum temperature records being broken. The current ratio across the United States is approximately 2 to 1, providing further evidence of a significant warming trend.

Current trends for increased precipitation in the northern Great Plains are projected to become even more pronounced, while the southern Great Plains will continue to become drier by mid-century and later. The greatest increases for the northern Great Plains states so far have been in North and South Dakota, eastern Montana and most of eastern Nebraska. Little change in precipitation in the winter and spring months is expected for Nebraska. Increases in the summer and fall months are expected to be minimal and may be reduced during the summer months in the state. An increase in the percentage of average annual precipitation falling in heavy rainfall events has been observed for portions of the northern Great Plains states, including eastern Nebraska, and the Midwest. This trend is expected to continue in the decades ahead. Flood magnitude has been increasing because of the increase in heavy precipitation events. Soil moisture is projected to decrease by 5-10% by the end of the century, if the high emissions scenario ensues.

A major concern for Nebraska and other central Great Plains states is the current and continued large projected reduction in snowpack for the central and northern Rocky Mountains. This is due to both a reduction in overall snowfall and warmer conditions, meaning more rain and less snow, even in winter. Flows in the Platte and Missouri rivers during the summer months critically depend on the slow release of water as the snowpack melts. These summer flows could be greatly reduced in coming years.

Drought is a critical issue for Nebraska. This was demonstrated clearly during 2012, which was the driest and hottest year for the state based on the climatological record going back to 1895. Although the long-term climatological record does not yet show any trends in drought frequency or severity when considering drought at a national perspective, there is some evidence of more frequent and severe droughts recently in the western and southwestern United States, respectively. Looking ahead, however, the expectation is that drought frequency and severity in Nebraska would increase – particularly during the summer months – because of the combination of increasing temperatures and the increased seasonal variability in precipitation that is likely to occur. Temperature increases could result in widespread drying over the United States in the latter half of the twenty-first century, with severe drought being the new climate normal in parts of the central and western United States.

Implications of Projected Climate Changes in Nebraska

Current and projected changes in temperature will have positive benefits for some and negative consequences for others, typically referred to as winners and losers. However, the changes in climate currently being observed extend well beyond temperature and include changes in precipitation amounts, seasonal distribution, intensity and form, that is less snowfall. Changes in the observed frequency and intensity of extreme events are of serious concern today and for the future because of the economic, social and environmental costs associated with responding to, recovering from and preparing for these extreme events in the near and longer term.

To address the implications of observed and projected changes in climate on particular sectors, experts with knowledge of and practical experience in the principal sectors of importance to Nebraska were invited to prepare commentaries for the UNL report. The basis for these commentaries was the information contained in the recently released National Climate Assessment Report. The key sectors chosen for inclusion in this report were water resources; energy supply and use; agriculture; forests; human health; ecosystems; urban systems, infrastructure and vulnerability; and rural communities. These commentaries raise serious concerns about how the projected changes in climate will impact Nebraska, and they provide a starting point for discussions about the actions that we should take to adapt to the changes in each sector.

It is critically important to point out that the implications of and potential impacts associated with observed and projected changes in climate will be closely associated with the management practices employed in these specific sectors. For example, the impacts of projected changes in climate on the productivity of a specific farm will be dependent on the ability of that producer to adapt to these changes as they occur, and the producer's access to new and innovative technologies that facilitate the adaptation process. These early adapters will be better able to cope with changes as they occur.

The UNL climate change report documents many of the key challenges that Nebraska will face as a result of climate change. Imbedded in each of these challenges are opportunities. A key takeaway message from the report is that, with this knowledge in hand, we can identify actions that need to be implemented to avoid or reduce the deleterious effects of climate change for Nebraska. Action now is preferable and more cost effective than reaction later.

An electronic copy of the UNL climate report, *Understanding and Assessing Climate Change: Implications for Nebraska,* can be downloaded from http://go.unl.edu/climatechange.

Report authors:
Deborah Bathke
Bob Oglesby
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Understanding and Assessing Climate Change: Implications for Nebraska

A Synthesis Report to Support Decision Making
and Natural Resource Management
in a Changing Climate

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Top - The Sand Hills of central Nebraska. Photo by Jim Swinehart, University of Nebraska–Lincoln
Middle left - Sandhill cranes on the Platte River. Photo by NEBRASKAland Magazine/Nebraska Game and Parks Commission
Middle right - Irrigated corn with a center pivot system. Photo by Ken Dewey, University of Nebraska–Lincoln
Bottom - Aerial view of Lincoln, Nebraska including Memorial Stadium (left) and the Pinnacle Bank Arena (right). Photo by the Lincoln Journal Star

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FOREWORD

As the Land-Grant University for the people of Nebraska since 1869, the University of Nebraska-Lincoln has educated generations of our citizens, expanded our understanding of the greater universe through scholarly research, and effectively transferred knowledge from research to practice in our daily lives. This tri-fold mission of teaching, scholarly research, and extension to the public has never been more important in our 145-year history than in the current early decades of the 21st century.

As we plan for the next hundred years, a thorough understanding of our changing climate is needed. The impacts of climate variability have been visibly experienced in Nebraska and the northern Great Plains of the United States in the past decade, particularly in terms of a change in the length of the growing season and in greater variability in temperature and precipitation. Combined with the expected increase in the global population to 9.6 billion by 2050 that is expected to exert significant increased pressures on the world's water and land resources, it is particularly important to assess with all available information, what the current models tell us regarding the potential impacts of climate change on our state and its critically important natural resources in the near future and longer term. This is particularly important for the internationally leading agriculture and food sector of our state.

This report was commissioned by the UNL Institute of Agriculture and Natural Resources (IANR) with the objective of evaluating and summarizing the existing scientific literature related to our changing climate. Scientists from the IANR's School of Natural Resources and the Department of Earth and Atmospheric Sciences in the College of Arts and Sciences have been the principal contributors to the report under the able leadership of long-time, internationally leading applied climate scientist Professor Don Wilhite. Their efforts have resulted in a timely and seminal reference for state and local policy-makers, government agency leaders, private industry, and indeed all citizens of our great state.

The efforts of the faculty and staff of UNL to produce this report using the full body of knowledge available from the scientific literature are greatly appreciated. It is my, and their, hope that the report will be highly useful in planning how to successfully address the needs of the state of Nebraska and its people in the decades ahead in the face of increasing climate variability and change.

Ronnie D. Green, Ph.D.
Vice President, Agriculture and Natural Resources
University of Nebraska
Harlan Vice Chancellor, Institute of Agriculture and Natural Resources
University of Nebraska-Lincoln

ACKNOWLEDGEMENTS

The authors acknowledge Ronnie Green, Vice President, Agriculture and Natural Resources University of Nebraska, and Harlan Vice Chancellor, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, for his support of the preparation of this report. He has been committed to providing Nebraska's citizens with access to the current state of knowledge on climate change science and the implications of this information for the state.

We also acknowledge the contributions of the many experts who provided their interpretations of the implications of climate change for various sectors of importance to the state. Their commentaries will be invaluable to state agencies, University of Nebraska faculty, and the public by promoting a greater awareness across the state about the implications of this important environmental issue and the range of adaptation and mitigation actions that should be considered for adoption.

To the numerous other experts who provided input to the report in various capacities, we acknowledge their contributions. However, the lead authors assume full responsibility for the content of this report.

We also acknowledge the assistance of Deborah Wood for the countless hours she spent editing the report. Her keen eye helped to blend the contributions of the lead authors into what we hope is a coherent and science-based report. Dee Ebbeka is acknowledged for the layout and design of the final report. Her artistic eye helped to bring this report to life.

Finally, we would like to acknowledge Senator Ken Haar for his dedication and commitment to bringing the information contained in this report to the attention of the Nebraska legislature and every citizen of the State of Nebraska. From the beginning of this process, his goal was to move the state and its decision makers from a state of complacency to one of action on this important topic. In the end, we hope this report will help to achieve that goal.

ABOUT THE AUTHORS

Deborah Bathke is an assistant professor of practice in the meteorology-climatology program of the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln and is affiliated with the National Drought Mitigation Center. Deborah received her BS and MS degrees from the University of Nebraska-Lincoln in 1995 and 1998, respectively, and a PhD from The Ohio State University in 2004. Before relocating to UNL in 2008, Deborah served as the assistant state climatologist in New Mexico, where she chaired the state's Drought Monitoring Working Group, served as a member of the Climate Change Water Resources Impact Working Group, and was an investigator in the Climate Assessment for the Southwest program. She currently serves as a member of the Program Implementation Team and co-chairs the Engaging Preparedness Communities Technical Working Group of the National Integrated Drought Information System. Her current research interests include the development and evaluation of climate information and decision-support tools; capacity building for climate resiliency; and public participation, education, and engagement in drought planning.

Robert "Bob" Oglesby is a professor of climate modeling at the University of Nebraska-Lincoln, with joint appointments in the Department of Earth and Atmospheric Sciences and the School of Natural Resources. Bob received his BS in physical geography from the University of California, Davis, in 1985 and his PhD in geophysical fluid dynamics from Yale University in 1990. Before arriving at UNL in 2006, he was a senior scientist for 5 years at NASA and prior to that spent 10 years on the faculty of Purdue University. Bob's research interests include the causes of drought, the impact of deforestation on climate, and key mechanisms of climate change, both past and future. He has authored or co-authored more than 100 refereed journal papers and book chapters on these subjects. Bob is also currently involved with in-country training in the development and use of high-resolution climate change models for vulnerability and impacts studies in Latin America and Asia.

Clint Rowe is a professor in the meteorology-climatology program of the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln, where he has been on the faculty for more than 25 years. Clint received his PhD in climatology from the University of Delaware in 1988. Clint's research interests are focused on the interaction between the land surface and the atmosphere. His primary tools in this endeavor are computer simulation models of the land surface and the atmosphere, although he also has been involved in several observational field programs (in Greenland and the Nebraska Sand Hills). With support from the University of Nebraska's Holland Computer Center, Clint and colleague Bob Oglesby have established a research group dedicated to filling a major gap in climate change research capability at the regional, national, and international levels: the need for accurate and precise information on climate change at local and regional scales that will enable more accurate projections for informed decision making about adaptation to climate change. As part of this effort, they have conducted downscaling simulations of global climate model output for Mesoamerica, Bolivia, and South and Southeast Asia. Moreover, they have conducted (and continue to conduct) training workshops in Mesoamerica and Asia to make this information available in an understandable and accessible format to the stakeholders and policy makers who must develop and implement strategies for adapting to climate change.

Donald Wilhite is a professor of applied climate science in the School of Natural Resources at the University of Nebraska-Lincoln. He joined the UNL faculty in 1977. Dr. Wilhite received his MA from Arizona State University in 1969 and his PhD from the University of Nebraska-Lincoln in 1975. He was the founding director of the National Drought Mitigation Center at the University of Nebraska and served in this capacity from 1995 to 2007. Dr. Wilhite served as director of the School of Natural Resources from 2007 to 2012. His research and outreach activities have focused on issues of drought monitoring, planning, mitigation, and policy and the use of climate information in decision making. Dr. Wilhite recently chaired the International Organizing Committee for the High-level Meeting on National Drought Policy, sponsored by the World Meteorological Organization, the U.N. Food and Agriculture Organization, and the U.N. Convention to Combat Desertification. Dr. Wilhite chairs the management and advisory committees of the Integrated Drought Management Program, recently launched by WMO and the Global Water Partnership. In 2013, Dr. Wilhite was elected a Fellow in the American Meteorological Society. He has authored or co-authored more than 150 journal articles, monographs, book chapters, and technical reports. Dr. Wilhite is editor of numerous books on drought and drought management, including Drought and Water Crises (CRC Press, 2005) and Drought: A Global Assessment (Routledge, 2000).

EXECUTIVE SUMMARY

Globally, we face significant economic, social, and environmental risks as we confront the challenges associated with climate change. The body of scientific evidence confirms with a high degree of certainty that human activities in the form of increased concentrations of greenhouse gases (GHGs) since the beginning of the Industrial Revolution, changes in land use, and other factors are the primary cause for the warming that the planet has experienced, especially in recent decades.

Is there a debate within the scientific community with regard to observed changes in climate and human activities as the principal causal factor? The short answer here is "no", at least certainly not among climate scientists—that is, those scientists who have actual expertise in the study of climate and climate change. For more than a decade, there has been broad and overwhelming consensus within the climate science community that the human-induced effects on climate change are both very real and very large. The debate in 2014 is restricted to precisely how these changes will play out and what actions we will need to take to adapt to and mitigate the effects of these changes.

The magnitude and rapidity of the projected changes in climate are unprecedented. The implications of these changes for the health of our planet, and the legacy we will leave to our children, our grandchildren and future generations are of vital concern. Therefore, it is imperative that we develop strategies now to adapt to the multitude of changes we are experiencing and will continue to experience in our climate. This process of adaptation must begin at the local level, where these changes are being observed and their impacts felt. However, global agreements on the reduction of GHG emissions are a critical part of the solution in terms of mitigating as much future warming as possible.

The approach taken in this report is to review the voluminous scientific literature on the subject and interpret—given time and resource constraints—our current understanding of the science of climate change and the implications of projections of climate change for Nebraska. The goal of this report is to inform policy makers, natural resource managers, and the public about 1) the state of the science on climate change, 2) current projections for ongoing changes over the twenty-first century, 3) current and potential future impacts, and 4) the management and policy implications of these changes. Hopefully, this report will lead to a higher degree of awareness and the initiation of timely and appropriate strategic actions that enable Nebraskans to prepare for and adapt to current and future changes in our climate.

The Earth's Climate System

Changes to the components of the earth's climate system are caused by changes in forcings, or external factors, that may be either positive (lead to warming) or negative (lead to cooling). Climate forcings can be classified as natural or anthropogenic—that is, human-induced. Examples of natural forcings include solar variability and volcanic eruptions, while anthropogenic forcings include GHG emissions, aerosol production, and land-use changes. Changes in natural forcings have always occurred and continue today, having produced climate change and variability throughout the earth's history; only recently have anthropogenic forcings become large enough to significantly affect the climate system.

Nearly all the energy driving the climate system comes from the sun. Although solar output varies over time and has led to climate changes during the earth's geologic history, changes in solar radiation cannot account for the warming observed over the past 30 years, during which accurate measurements of solar output have been made. In the absence of solar forcing, the largest climate forcing is due to changes in atmospheric composition, particularly of GHGs and aerosols. Global climate models cannot reproduce the recent observed warming without including anthropogenic forcings (particularly GHG emissions).

Evidence that human activities influence the global climate system continues to accumulate because of an increased understanding of the climate system and its response to natural and anthropogenic factors, more and better observations, and improved climate models. In fact, in their latest assessment report, the Intergovernmental Panel on Climate Change (IPCC) now states with 95% confidence that human influence is the main cause of the observed warming in the atmosphere and oceans and other indicators of climate change and that continued emissions of GHGs will cause further warming and changes in these components of the climate system. Before the large-scale use of fossil fuels for energy (starting during the Industrial Revolution), the concentrations of the major GHGs were remarkably constant during human history. Since then, the concentration of these gases has risen—slowly at first, then more rapidly since the middle of the twentieth century. Furthermore, scientists can say with very high confidence that the rate of increase of these gases is unprecedented in the last 22,000 years—and with high confidence over the last ~800,000 years.

Evidence for a Changing Climate

Multiple lines of evidence show that the earth's climate has changed on global, regional, and local scales. Scientists from around the world have collected this evidence from weather stations, satellites, buoys, and other observational networks. When taken together, the evidence clearly shows that our planet is warming. However, temperature change represents only one aspect of a changing climate. Changes in rainfall, increased melting of snow and ice, rising sea levels, and increasing sea surface temperatures are only a few of the key indicators of a changing climate.

Although the globe as a whole is getting warmer, observations show that changes in climate have not been uniform in space and time. Some areas have cooled while others have warmed, a reflection of normal climate variability and differing controls on regional climate. Likewise, some areas have experienced increased droughts while others have had more floods. Changes in Nebraska's climate are occurring within the context of these global and regional changes.

Past and Projected Changes in Nebraska's Climate

Nebraska has experienced an overall warming of about 1°F since 1895. When this is separated into daytime highs and nighttime lows, we find that the trend in low temperatures is greater than the trend in high temperatures, both of which show an overall warming. These trends are consistent with the changes experienced across the Plains states in general, which show a warming that is highest in winter and spring and a greater warming for the nighttime lows than for daytime highs. By far, the vast majority of this warming has occurred during the winter months, with minimum temperatures rising 2.0-4.0°F per century and maximum temperature increases of 1.0-2.5°F per century. Summer minimum temperatures have shown an increase of 0.5-1.0°F per century at most locations, but maximum temperature trends generally range from -0.5 to +0.5°F per century. Unlike temperature, however, there is no discernable trend in mean annual precipitation in Nebraska. Since 1895, the length of the frost-free season has increased by 5 to 25 days across Nebraska, and on average statewide by more than one week. The length of the frost-free season will continue to increase in future decades.

Projected temperature changes for Nebraska range from an increase of 4-5°F (low emission scenarios) to 8-9°F (high emission scenarios) by the last quarter of the twenty-first century (2071-2099). This range is based on our current understanding of the climate system under a variety of future emissions scenarios. The range of temperature projections emphasizes the fact that the largest uncertainty in projecting climate change beyond the next few decades is the level of heat-trapping gas emissions that will continue to be emitted into the atmosphere and not because of model uncertainty.

Under both low and high emissions scenarios, the number of high temperature stress days over 100°F is projected to increase substantially in Nebraska and the Great Plains region. By mid-century (2041-2070), this increase for Nebraska would equate to experiencing typical summer temperatures equivalent to those experienced during the 2012 drought and heat wave. The number of warm nights, defined as the number of nights with the minimum temperature remaining above 80°F for the southern Plains and above 60°F for the northern Plains, is expected to increase dramatically. For Nebraska, the number of warm nights is expected to increase by an additional 20-25 nights for the low emissions scenario and 25-40 nights for the high emissions scenario.

With the projected increase in global and regional temperatures, there has been an increase in heat wave events occurring around the world. This can be demonstrated by the ratio of maximum temperature records being broken in comparison to the number of minimum temperature records being broken. The current ratio across the United States is approximately 2 to 1, providing further evidence of a significant warming trend.

Current trends for increased precipitation in the northern Great Plains are projected to become even more pronounced, while the southern Great Plains will continue to become drier by mid-century and later. The greatest increases for the northern Great Plains states so far have been in North and South Dakota, eastern Montana, and most of eastern Nebraska. Little change in precipitation in the winter and spring months is expected for Nebraska. Any increases in the summer and fall months are expected to be minimal and precipitation may be reduced during the summer months in the state. An increase in the percentage of average annual precipitation falling in heavy rainfall events has been observed for portions of the northern Great Plains states, including eastern Nebraska, and the Midwest. This trend is expected to continue in the decades ahead. Flood magnitude has been increasing because of the increase in heavy precipitation events. Soil moisture is projected to decrease by 5-10% by the end of the century, if the high emissions scenario ensues.

A major concern for Nebraska and other central Great Plains states is the current and continued large projected reduction in snowpack for the central and northern Rocky Mountains. This is due to both a reduction in overall precipitation (rain and snow) and warmer conditions, meaning more rain and less snow, even in winter. Flows in the Platte and Missouri rivers during the summer months critically depend on the slow release of water as the snowpack melts. These summer flows could be greatly reduced in coming years.

Human activities local to Nebraska can also be important in terms of how they influence the climate at the microclimatic level. In particular, the advent of large-scale irrigation in Nebraska since the 1960s has kept the summertime climate in Nebraska cooler and wetter than it otherwise would have been. However, if reduced water availability curtails irrigation in the state, then the microclimatic effects of irrigation will be lessened in the future, exacerbating the effects of anthropogenic climate change.

Drought is a critical issue for Nebraska. This was demonstrated clearly during 2012, which was the driest and hottest year for the state based on the climatological record going back to 1895. Although the long-term climatological record does not yet show any trends in drought frequency or severity from a national perspective, there is some evidence of more frequent and severe droughts recently in the western and southwestern United States, respectively. Looking ahead, however, the expectation is that drought frequency and severity in Nebraska would increase—particularly during the summer months—because of the combination of increasing temperatures and the increased seasonal variability in precipitation that is likely to occur. Modeling studies show that drought, as indicated by the commonly used Palmer Drought Severity Index (PDSI), is expected to increase in the future. The PDSI uses temperature and precipitation data to estimate relative dryness. Temperature increases could result in widespread drying over the United States in the latter half of the twenty-first century, with severe drought being the new climate normal in parts of the central and western United States.

Implications of Projected Climate Changes in Nebraska

Current and projected changes in temperature will have positive benefits for some and negative consequences for others, typically referred to as winners and losers. However, the changes in climate currently being observed extend well beyond temperature and include changes in precipitation amounts, seasonal distribution, intensity, and form (snow versus rain). Changes in the observed frequency and intensity of extreme events are of serious concern today and for the future because of the economic, social, and environmental costs associated with responding to, recovering from, and preparing for these extreme events in the near and longer term.

To address the implications of observed and projected changes in climate on particular sectors, experts with knowledge of, and practical experience in, the principal sectors of importance to Nebraska were invited to prepare commentaries for this report. The basis for these commentaries was the information contained in the recently released National Climate Assessment Report. The key sectors chosen for inclusion in the Nebraska climate change report were water resources; energy supply and use; agriculture; forests; human health; ecosystems; urban systems, infrastructure and vulnerability; and rural communities. An assessment of the importance of observed and projected changes in climate for the insurance industry, both globally and locally, was also completed. These commentaries raise serious concerns about how the projected changes in climate will impact Nebraska, and they provide a starting point for discussions about the actions that we should take to adapt to the changes in each sector.

It is critically important to point out that the implications of and potential impacts associated with observed and projected changes in climate will be closely associated with the management practices employed in these specific sectors. For example, the impacts of projected changes in climate on the productivity of a specific farm will be dependent on the ability of that producer to adapt to these changes as they occur, and the producer's access to new and innovative technologies that facilitate the adaptation process. Early adapters will be better able to cope with changes as they occur.

This report documents many of the key challenges that Nebraska will face as a result of climate change. Imbedded in each of these challenges are opportunities. A key takeaway message from the report is that, with this knowledge in hand, we can identify actions that need to be implemented to avoid or reduce the deleterious effects of climate change in Nebraska. Action now is preferable and more cost effective than reaction later.

CHAPTER 1

INTRODUCTION

Globally and locally, we face significant economic, social, and environmental risks as we confront the challenges associated with climate change (NCA, 2014; Bloomberg et al., 2014; White House, 2014). The body of scientific evidence confirms with a high degree of certainty that human activities in the form of increased concentrations of Greenhouse Gases (GHGs) since the beginning of the Industrial Revolution, changes in land use, and other factors are the primary cause for the warming that the planet has experienced, especially in recent decades. Projected changes, and the rapidity of these changes, are unprecedented. The implications of these changes for the health of our planet and the legacy we will leave to our children, our grandchildren, and future generations are of vital concern.

While countries work to adopt controls to reduce the emissions of key GHGs in order to mitigate future warming, observations clearly demonstrate that we have already experienced a significant warming of the planet, and the impacts of this warming have been observed worldwide, although, as expected, the degree of warming varies regionally. Projections are for the warming to continue, even if we are able to adopt stricter emission controls of GHGs. Therefore, it is imperative that we develop strategies now to adapt to the multitude of changes that we are experiencing and will continue to experience in our climate. This process of adaptation must begin at the local level where these changes are being observed and their impacts felt.

Nebraska lies in the Great Plains region of the United States. Its climate is always variable and subject to extremes, and can be, at times, harsh. For example, portions of the state experienced severe flooding in 2011 and the entire state was engulfed in an extreme drought in 2012, our driest and warmest year on record, when portions of the state recorded maximum daily temperatures exceeding 100°F for 30 days or more. The average annual precipitation gradient across the state, ranging from an average annual total of 36 inches in the extreme southeast to less than 15 inches in the Panhandle, is equal to the precipitation change from the east coast of the United States to the Missouri River, but is highly variable from year to year. Nebraska's residents have adapted to its variable weather conditions and will have to continue to adapt to the projected changes in our climate, some of which have already been observed.

The approach taken in preparing this report was to review the voluminous scientific literature on the subject and interpret, given time and resource constraints, our current understanding of the science of climate change and the implications of projections of climate change for Nebraska. Among the scores of reports and hundreds of scientific articles available to us as part of this literature review process, we were fortunate to have the most recent series of reports from the Intergovernmental Panel on Climate Change (IPCC) and the Third National Climate Assessment report issued in May 2014 from the U.S. Global Change Research Program. These reports, which are periodically updated, underscore how our understanding of climate has been enriched in recent years as a result of the multitude of research efforts being conducted from the global to the local scale.

The goal of this report is to inform policy makers, natural resource managers, and the public about the state of the science on climate change, current projections for ongoing changes over the twenty-first century, current and potential future impacts, and the management and policy implications of these changes. Hopefully, this report will lead to a higher degree of awareness and the initiation of timely and appropriate strategic actions that will enable Nebraskans to prepare for and adapt to future changes to our climate.

Brian Fuchs, University of Nebraska–Lincoln

Extensive ground cracking in a sorghum field eight miles north of Lincoln as a result of the severe drought that gripped the area, June 2002.

Box 1.1
The Intergovernmental Panel on Climate Change (IPCC) and the National Climate Assessment (NCA)

IPCC, Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge of climate change and its potential environmental and socioeconomic impacts. The IPCC reviews and assesses the most recent scientific, technical, and socioeconomic information produced worldwide relevant to the understanding of climate change.

NCA, National Climate Assessment

The National Climate Assessment summarizes the impacts of climate change on the United States, now and in the future. It is congressionally mandated under the U.S. Global Change Research Program. The NCA informs the nation about observed changes, the current status of the climate, and anticipated trends for the future; integrates scientific information from multiple sources and sectors to highlight key findings and significant gaps in knowledge; establishes consistent methods for evaluating climate impacts in the United States in the context of broader *global change*; and is used by the national, state, and local governments, citizens, communities, and businesses as they create more sustainable and environmentally sound plans for the future.

Jim Swinehart, University of Nebraska–Lincoln

The sun sets over the Sand Hills of north-central Nebraska.

CHAPTER 2

CLIMATE SCIENCE: CONCEPTS AND DEFINITIONS

Basic Climate and Climate Change Science

The distinction between weather and climate is often misunderstood. Weather is what you can look out the window and actually see. That is, it represents the condition of the atmosphere at a given time and place. It can be described by variables such as temperature, precipitation, humidity, and clouds. Climate, on the other hand, represents a longer-term or "average" state of the atmosphere. Climate is typically defined in terms of 30-year means as well as the variability around those means from year to year and decade to decade. Climate also includes the magnitude and frequency of occurrence of extreme events, such as heat waves, cold snaps, flooding rains, blizzards, and severe droughts. A period of cold weather or a cooler than normal winter (or spring or summer or fall), a cold winter and heavy snowfall season, or a below-average number of high temperature days during the summer months is interpreted by some as evidence that global warming is not occurring. In actuality, these short-term events are just an expression of the normal variability of weather and the factors that drive weather patterns.

This definition of climate assumes the statistical properties (such as mean, variance, etc.) do not change over time for a given climate. In practice, climate varies on time scales both longer and shorter than 30 years. On the shortest time scales, we enter the realm of weather. Variability on time scales of a few years to a few decades—in other words, shorter than a climatic averaging period—is usually referred to as *climatic variability*. Variability on time scales longer than a few decades (longer than a standard climatic averaging period) is usually referred to as *climatic change*. Climate variability and climate change are frequently used, and misused, terms. Essentially, there is no meaningful difference between them, apart from the time scale over which they occur. The schematic shown in Figure 2.1 illustrates this concept. Note that some variability occurs on *all* time scales. At some scales, however, the variability is less than at time scales shorter and longer. For example, at the shortest time scales, an averaging period of one hour can distinguish very short-term phenomena—such as a gust of wind or individual cumulus cloud—from the synoptic weather associated in the mid latitudes with the passage every few days of large-scale high and low pressure systems. Key sources of climatic variability for the central United States will be discussed below in more detail.

The earth's climate system comprises five major components: the *atmosphere*, the *hydrosphere* (oceans, lakes, rivers, etc.), the *cryosphere* (ice sheets, glaciers, and sea ice), the *biosphere* (vegetation and soils) and the *lithosphere* (volcanoes, orography, weathering). Even if we are most interested in the atmosphere (that component in which we live), to fully understand the climate system we must understand how all of these components work. In particular, we need to concern ourselves with how these components interact through numerous physical processes (primarily exchanges of heat, matter, and momentum between components) to produce the earth's climate. A change in any of these components can result in changes in other components through these interactions.

Figure 2.1. The classic spectrum of climate change. Note that variability occurs on all time scales, but to a greater or a lesser degree. (Source: K. Maasch, University of Maine)

Changes to the components of the earth's climate system are caused by changes in forcings, or external factors, that may be either positive (lead to warming) or negative (lead to cooling). Climate forcings can be classified as natural or anthropogenic (human-induced). Examples of natural forcings include solar variability and volcanic eruptions, while anthropogenic forcings include greenhouse gas (GHG) emissions, aerosol production, and land-use changes. Moreover, through various feedbacks, the initial change may grow (positive feedbacks) or be reduced (negative feedbacks). Changes in natural forcings have always occurred and continue today, having produced climate change and variability throughout the earth's history; only recently have anthropogenic forcings become large enough to significantly affect the climate system.

Nearly all the energy driving the climate system comes from the sun. Although solar output varies over time and has led to climate changes during the earth's geologic history, changes in solar radiation cannot account for the warming observed over the past 30 years, during which accurate measurements of solar output have been made. In the absence of solar forcing, the largest climate forcing is due to changes in atmospheric composition, particularly of GHGs and aerosols. GHGs occur naturally, and pre-industrial concentrations are responsible for keeping the earth's average temperature nearly 58°F higher than if no GHGs were present (i.e., the *natural greenhouse effect*) (Figure 2.2). Higher concentrations of GHGs due to human activities – in the absence of any feedbacks – would undoubtedly lead to higher temperatures. It is this *enhanced greenhouse effect* that is the subject of concern today. Although the basic effect is atmospheric warming, this leads to other effects such as changes in precipitation patterns, glacier and ice sheet melting, and sea level rises.

Weather and climate models are used to predict weather in the near future and to study how the climate system responds to various types of changes, or *forcings*. (The reader is referred to Chapter 6 for a discussion of climate models.) Global climate models cannot reproduce the recent observed warming without including anthropogenic forcings (particularly GHG emissions). As it becomes increasingly clear that human-induced climate change is occurring, the Intergovernmental Panel on Climate Change (IPCC) emphasizes that the focus of scientific research is shifting from basic global climate science to understanding and coping with the impacts of climate change. Results at the global scale are useful

Figure 2.2. The greenhouse effect. (Source: Le Treut et al., 2007)

Box 2.1
Forcings and Feedbacks in the Climate System

In the context of the climate system, a *forcing* is an external factor that has an effect on the system. Forcings can be *natural*, such as changes in solar energy input to the system or volcanic eruptions introducing gases and particulates into the atmosphere. Human activities can also produce forcings on the climate system. These forcings, referred to as *anthropogenic*, include changes in greenhouse gas concentrations in the atmosphere—due primarily to fossil fuel combustion and other industrial activities—and land use changes such as deforestation and conversion to agricultural fields.

A *feedback* is a process internal to the climate system that modifies the effect of a forcing. Feedbacks can either be *positive* (pushing the system in the same direction as the forcing) or *negative* (working against the forcing to offset its effect). An example of a positive feedback in the climate system is the melting of snow and ice as a result of increasing temperatures, exposing darker surfaces which absorb more sunlight, further increasing temperature. A negative feedback in the climate system would occur if increasing temperatures resulted in an increase of clouds that reflect solar radiation back to space, which would work to reduce the surface temperature.

In some cases, the same factor may play the role of a forcing or a feedback, depending on the context. For example, CO_2 added by human activities is considered a forcing, as the change is caused by something external to the climate system. As the earth's temperature increases, CO_2 is released from oceans and regions of permafrost. This is considered a feedback, as it is a response internal to the climate system. This feedback has occurred in past glacial/interglacial transitions and is likely to occur as the climate system warms in response to anthropogenic forcing from CO_2 emissions.

for indicating the general nature and large-scale patterns of climate change, but are not very robust at the local or regional scale (typically 5-15 km). These latter scales require the use of *regional climate models*.

According to IPCC, a climate change *impact* means: *A specific change in a system caused by exposure to climate change*. In the context of climate science, *vulnerability* refers to the degree to which a natural or human system is susceptible to, or unable to cope with, adverse effects of a climate change impact. The assessment of key vulnerabilities involves substantial *scientific uncertainties* as well as *value judgments*.

Natural versus Human-Induced Climate Change

Climate has always changed in the past; we have every good reason to think this will continue. Indeed, as mentioned above, this climate change as it naturally occurs is simply an expression of variability between the full atmosphere-ocean-land surface-cryosphere-lithosphere components of the climate system. Most interannual to decadal scale variability is due to fluctuations between the atmosphere and the oceans. "Natural" climate change, simply variability on longer time scales, is attributed to effects such as changes in the orientation of the earth-sun orbit, long-term fluctuations in solar output, and the changing configuration of the continents. These changes directly affect climate and influence other climatically important processes, such as the carbon cycle.

Human behavior impacts these otherwise natural processes in two ways:

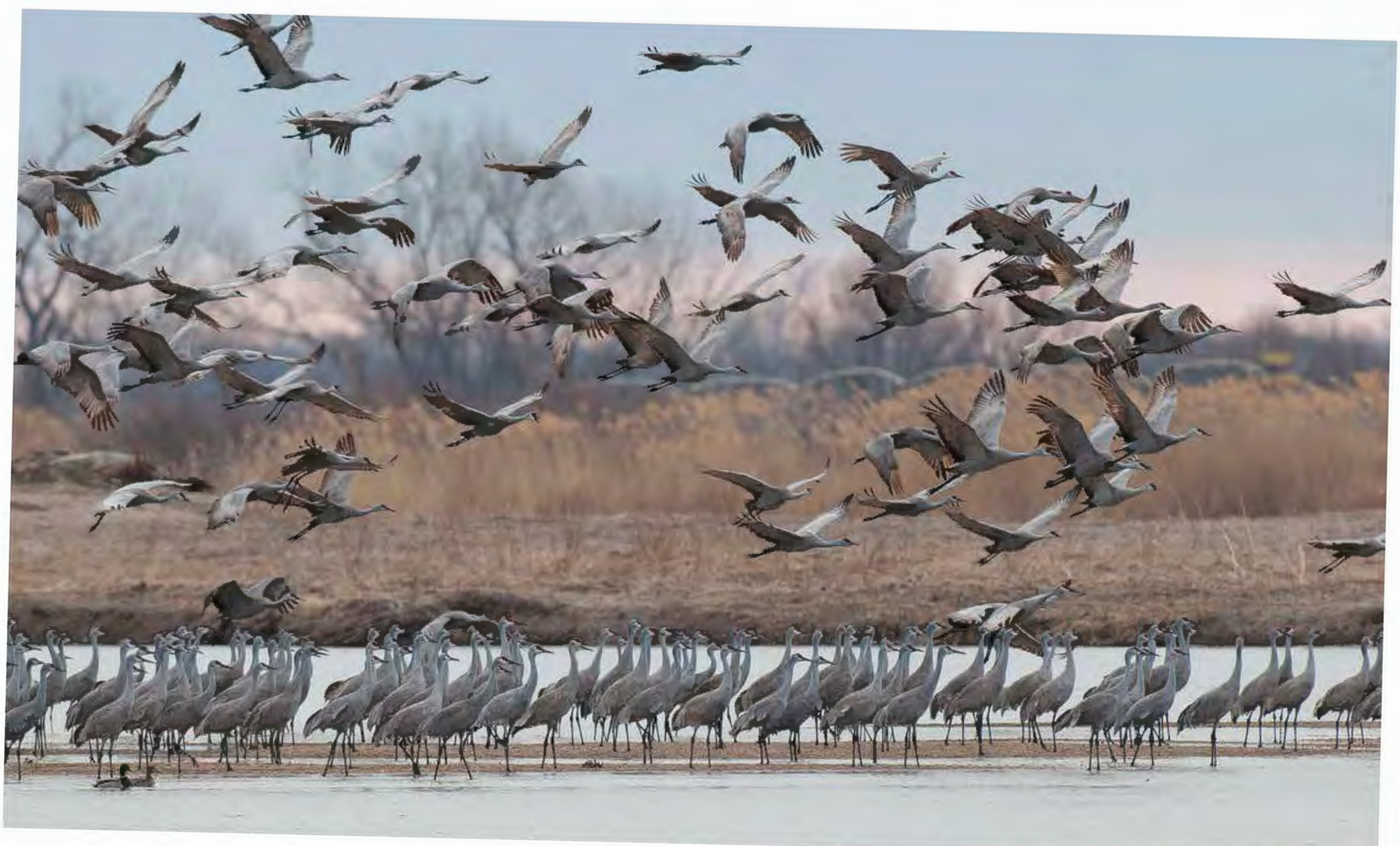
1. The type or nature of the change. Human activities are clearly leading to warming, while the natural system would otherwise indicate neutral conditions to a slight cooling.
2. The rapidity of the change. In particular, most natural processes of climate change develop fairly slowly, that is, over a period of centuries to millennia. The human-induced global warming, on the other hand, is unfolding in just a few decades—that is, before the end of the twenty-first century, and beyond if concentrations of GHGs continue on their current trajectory.

Sources of Climate Variability on Interannual to Interdecadal Time Scales

The only true cyclical behavior of the climate system involves the diurnal cycle (night versus day) and the annual cycle (the seasons). Other sources of variability involve interactions between various components of the climate system, especially the atmosphere and oceans. The best known of these sources of variability on interannual to interdecadal time scales is probably the El Niño–Southern Oscillation, or ENSO. This refers to a coupled variation of ocean temperatures and atmospheric pressure at regular intervals over the equatorial Pacific Ocean. During the warm phase in particular, winters are generally warmer and wetter in Nebraska.

Recently, the so-called polar vortex, more properly associated with something called the Arctic Oscillation, has received considerable media attention. The Arctic Oscillation describes shifts in multiple features of the polar circulation: air pressure, temperature, and the strength and location of the jet stream. It represents a non-hemispheric-scale transfer of mass back and forth between the Arctic and mid-latitudes. During the *positive phase*, air pressure is lower than average over the Artic and higher than average over the mid-latitudes, and the jet stream is farther north than average and steers storms northward. This generally results in fewer cold air outbreaks over the mid-latitudes. During the *negative phase*, the jet stream shifts southward of its normal position and can develop waves that help steer frigid Arctic air southward.

It is important to recognize that the above phenomena relate to variations in ocean-atmosphere interactions. During a period of time (such as in the recent decade) when the rise in atmospheric temperatures lessens, it is because the ocean is gaining relatively more heat. During other intervals, atmospheric temperatures rise more sharply, with the ocean gaining relatively less heat. Water has a much higher specific heat than air; that is, it takes more energy to raise the temperature of water by 1°F than it takes to raise the temperature of the same mass of air by 1°F. Also, because the earth's oceans have much more mass than the atmosphere, the oceans can absorb a large amount of heat without the global ocean temperature increasing by as much as would the temperature of the atmosphere. This is the cause of the decadal "stair-step" rise in global temperatures seen from observations and climate model simulations.



NEBRASKAland Magazine/Nebraska Game and Parks Commission

Sandhill cranes take refuge in central Nebraska during their yearly migration. Reduced flows on the Platte River, due to declining snowpack in the Rockies and an increased frequency of drought, may alter the cranes' habitat.

CHAPTER 3

OBSERVED CHANGES IN CLIMATE

How Do We Know the Climate Has Changed?

Multiple lines of evidence show that the earth's climate has changed on global, regional, and local scales. Scientists from around the world have collected this evidence from weather stations, satellites, buoys, and other observational networks. When taken together, the evidence clearly shows that our planet is warming. However, temperature change only represents one aspect of a changing climate. Other indicators include changes in rainfall, increased melting of snow and ice, rising sea levels, and increasing sea surface temperatures (Figure 3.1).

The globe as a whole is getting warmer, but observations show that changes in climate have not been uniform in

Figure 3.1. These are just some of the indicators measured globally over many decades that show that the earth's climate is warming. White arrows indicate increasing trends, and black arrows indicate decreasing trends. All the indicators expected to increase in a warming world are, in fact, increasing, and all those expected to decrease in a warming world are decreasing. (Source: Walsh et al., 2014)

space and time. Some areas have cooled while others have warmed, a reflection of normal climate variability and differing regional climate controls. Likewise, some areas have experienced increased droughts while others have had more floods. Changes in Nebraska's climate are occurring within the context of these global and regional changes, and the consequent impacts and opportunities for Nebraska are related to changes occurring outside the United States. Thus, to understand the full impact of climate change on our state's economy and quality of life, it is necessary to first examine the broader picture of climate change.

Evidence from Global Records

Temperature

Observations from the land and oceans indicate that the earth's temperature is increasing (Figure 3.2). Clearly, temperatures today are warmer than they were when widespread record keeping began during the mid-1800s. This warming has been particularly marked since the

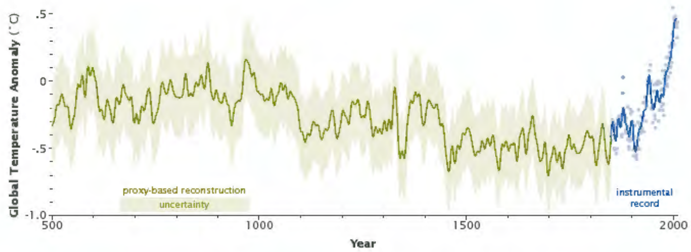


Figure 3.2. Reconstructed global temperature record for the last 2,000 years. (Source: NASA Earth Observatory, n.d.)

1970s, with every year since 1976 having an annual average temperature that is above the long-term (1880 to 2012) mean. In fact, July 2014 was the 353rd consecutive month with a global temperature above the twentieth century average (NOAA, 2014). Furthermore, the ten warmest years on record have occurred since 1997. When proxy sources, such as tree rings and ice cores, are used to extend the temperature record, it becomes clear that the rate of warming since the 1950s is unprecedented over at least the last 1,000 years (Hartmann et al., 2013).

From 1880 to 2012 the globe as a whole experienced a warming of approximately 1.5°F (Hartmann et al., 2013). The global temperature represents an average over the entire surface of the planet. This increase is not uniform. Local and regional changes differ because of variations in the main climate controls such as latitude, elevation, vegetation, water, and air and ocean currents. The largest rates of warming have primarily been in the Northern Hemisphere land areas, which have experienced temperature changes as high as 4.5°F. Other areas, such as the North Atlantic Ocean, have locally cooled as much as 1.1°F.

Why does it matter?

Although a few degrees of warming may not seem like much, it is significant because it represents a huge amount of energy—large enough to heat the world's land and oceans. The following sections will show that this small temperature change corresponds to significant changes in other components of the climate system.

Precipitation

Changes in precipitation are among the most important parts of climate change, but are more complicated to detect because of insufficient or unreliable data and the highly variable nature of precipitation over space and time. Global records indicate a trend of increased precipitation over the period 1901-2008 (Hartmann et al., 2013). However, trends for shorter periods of time show mixed results, with some datasets showing increases and others showing decreases.

Trends also do not describe the full range of precipitation changes that have occurred. Recent research indicates that climate change has caused a shift in global precipitation patterns through an intensification of the hydrologic cycle and a shift in atmospheric circulation (Marvel and Bonfils, 2013). Warmer temperatures lead to an increase in evaporation from oceans and land. But a warmer atmosphere can also hold more water in vapor form before it will saturate, and the vapor then condenses into clouds before forming rain or snow. Regions that already have ample rain and snow tend to become even wetter. This is because the atmosphere is usually close to saturation in these regions, even with warmer temperatures, and so during a precipitation event there is simply more water in the atmosphere available to precipitate out. Already dry regions, on the other hand, tend to become drier. A dry region is the result of insufficient water vapor in the atmosphere to achieve condensation and precipitation. The warmer atmosphere simply makes saturation that much more difficult to achieve. Further, shifting storm tracks and atmospheric circulation patterns change the transport of water vapor through the atmosphere. Regional changes are apparent in precipitation records, especially over mid-latitude Northern Hemisphere landmasses where precipitation records are generally more abundant and reliable. Much of the eastern United States and large parts of Europe show significant increases in precipitation while the parts of the U.S. Southwest and Pacific Northwest, Spain, and East Asia show significant decreases.

In addition to the amount of precipitation that falls, climate change also affects the form that precipitation takes. Studies in North America have found that for many regions, more precipitation is falling as rain rather than snow (Vaughan et al., 2013), which leads to significant changes in the hydrology of river basins, with further implications for reservoir storage and management.

Why does it matter?

Changes in precipitation impact runoff and groundwater recharge, affect the types of crops that can be grown, influence water pollution, alter the occurrence of flooding and drought, and determine the type and health of ecosystems, to name just a few effects. In places such as the western United States that depend heavily on snowpack as a principal water source, the gradual melting of snow to supply water during the summer is an important component of water management in the region. Reduced snow and a change in the melting regimen both result in a change in the intensity and timing of runoff and lead to greater water stress during the summer months and increased challenges for water management.

Snow and ice cover

One of the most visible indicators of climate change is the shrinking of the world's sea ice, ice sheets, and glaciers. Snow and ice are an integral part of the climate system and are particularly sensitive to a warming climate as well as to changes in precipitation. Data, consisting of direct observations and satellite images, indicate with high confidence that both the Greenland and Antarctic ice sheets have been losing mass and that the rates of ice loss have increased in recent decades. The total ice loss from both ice sheets over the period 1992 to 2012 was about 4260 gigatons, equivalent to about 0.05 inches in sea level rise (Vaughan et al., 2013).

Arctic and Antarctic sea ice, on the other hand, are showing different changes with time. Over the period 1974 to 2012, when satellite observations are available, these observations indicate that Arctic sea ice has decreased in thickness and extent, with the most notable changes occurring in summer. The average annual extent has decreased by 3.8% per decade, while decline at the end of summer has been even greater, with a decrease of 11% per decade (Vaughan et al., 2013). A record minimum extent was reached in September 2012, and the sixth lowest extent was recorded in 2013 (NSIDC, 2014). Over the same period of time, the annual mean Antarctic sea ice extent has increased at a rate of about 1.5% per decade, expanding to a record maximum extent in September 2013 (NSIDC, 2014). Scientists attribute this change to differences in the land-water distribution and wind and ocean currents in the Southern Hemisphere. However, substantial regional differences exist, with some areas increasing and others decreasing by as much as 4.3%.

Northern Hemisphere seasonal snow cover has also decreased significantly. The largest rate of change, a 53% decrease, occurred in June over the period of 1967-2012

(Vaughan et al., 2013). In places such as the western and central United States, this decrease is due, in part, to more wintertime precipitation falling as rain rather than snow.

It is important to note that snow and ice are not just passive indicators of a changing climate. Changes in each of these components can, in turn, cause further changes in the climate system through their influence on surface energy and moisture fluxes, precipitation, hydrology, and atmospheric and ocean circulation. For example, a decrease of ice cover causes a positive feedback (see Box 2.1) because ice is more reflective than land or water surfaces. Therefore, as ice cover decreases, more sunlight is absorbed by the earth's surface and the earth's surface warms even more—causing an accelerated rate of ice loss from glaciers, the Greenland ice sheet, and Arctic sea ice extent. The intensified melting from glaciers is considered a major cause of the observed changes in sea level (discussed in more detail in the next chapter).

Why does it matter?
The impacts resulting from snow and ice loss extend beyond physical changes to the climate system in the polar regions and have implications for many countries. Snow and ice loss also affects biological and social systems (Vaughan, 2013). In addition to raising sea levels, ice loss from glaciers and ice sheets may affect global circulation, salinity, and marine ecosystems. Reduced sea ice opens shipping lanes and increases access to natural resources. Increased glacial melt will initially increase flood risk and will severely reduce water supplies for communities in areas that depend on the seasonal melting of glaciers for their water supply, such as the South American Andes, the Canadian Western Prairies, the western United States, and Northwest China (Li et al., 2010; Schindler and Donahue, 2006; Barnett et al., 2005). Reduced seasonal snow cover will impact soil moisture, tourism, and wildlife habitats.

Oceans
Climate change is also leaving its mark on the world's oceans by raising sea levels, increasing the temperature and acidity of the water, altering oceanic circulation, and threatening ecosystems. These effects can be attributed to the fact that the oceans are a major sink for both heat and carbon dioxide for the planet. Not only does water cover more than 70% of the earth, it also has the ability to store large amounts of heat without an increase in temperature. The heat content of the ocean has increased dramatically in the last few decades. Analyses show that more than 90% of the excess heat energy created in the last few decades has gone to warming the oceans, resulting in an increase of about 0.18°F per decade in the near surface temperature over the period 1971-2010 (Rhein et al., 2013). These increasing temperatures are not limited to the surface; warming has also been observed in waters more than 6,000 feet below the surface.

Globally, sea level is rising, and at an accelerating rate, largely in response to climate change. Warmer ocean water expands and takes up more space, causing sea level to rise. The melting of land ice—glaciers, ice caps, and ice sheets—also adds water to the world's oceans. Tide gauges around the world have measured sea level since 1870, with satellite observations being added to the record in 1993. Together, these two sources of data indicate that global mean sea level has risen by about 7.5 inches between 1901 and 2010 (Rhein et al., 2013).

Additionally, warmer ocean temperatures affect the ability of the oceans to absorb carbon from the atmosphere. Physical and chemical properties of seawater mean that the oceans can hold up to 50 times more carbon than the atmosphere. About 30% of carbon emitted by the burning of fossil fuels has been sequestered in the ocean, reducing the rate at which carbon has accumulated in the atmosphere (Rhein et al., 2013). Observationally based evidence suggests that this level of absorption may not continue in the future (Khatiwala et al., 2009; McKinley et al., 2011). Cold oceans can absorb more carbon than warm oceans, so waters that are warming will have a decreased ability to absorb increasing emissions of carbon dioxide in the atmosphere. The downside of oceanic carbon absorption is that it creates carbonic acid, increasing the acidity of ocean waters.

Why does it matter?
Climate change puts the oceans and coasts at risk. The oceans are a major influence on weather and climate and a source of food, medicine, recreation, and employment. Furthermore, more than 44% of the world's population, approximately 3 billion people, live near the coasts (UN Atlas of the Oceans, 2010). Sea level rise may amplify storm surge, causing damages to buildings and loss of life; increase saltwater intrusion, threatening freshwater supplies; and cause shoreline erosion and degradation. The impact of Hurricane Sandy in the fall of 2012 along the east coast of the United States is but one example of the implications of sea level rise. Ocean acidification affects many marine organisms, particularly shelled animals, jeopardizing food supplies and employment for millions of people.

Extreme events
Worldwide, a record 41 weather-related natural disasters occurred in 2013. Despite the relatively large number,

extreme events, by definition, are infrequent. As a result, there are limited data for assessing changes over time, especially at the global scale. However, observations gathered since the 1950s indicate changes in some extremes (IPCC, 2012; 2013). Confidence in these changes depends on the availability of data and research on these phenomena and the locations at which they occur. Temperature data are generally the most complete and reliable and provide evidence that, for most global land areas, the number of warm days, warm nights, and heat waves has increased, while the number of cold days, cold nights, and cold waves has decreased. Other changes are typically less consistent, with results varying regionally (Table 3.1).

Table 3.1. Extreme weather and climate events: Global-scale assessment of recent observed changes and human contribution to the changes. Likelihood terminology and associated probability are as follows: Virtually certain - probability > 90%, Very likely – probability > 90%, likely – probability > 66%. (Adapted from Hartmann et. al., 2013)

Phenomenon	Direction of Trend	Assessment that changes occurred (typically since 1950 unless otherwise indicated)	Assessment of human contribution to observed changes
Warmer nights	⇧	Very likely (> 99% probability)	Very likely
Cold days	⬇	Very likely	Very likely
Warmer and more frequent hot days and nights	⇧	Very likely	Very likely
Warm spells/heat waves frequency and duration	⇧	Medium confidence on a global scale Likely in parts of Europe, Asia, and Austrailia	Likely
Frequency and intensity of heavy precipitation events and amount of precipitation during these events	⇧	Likely more land areas with increases than decreases	Medium confidence
Intensity and/or duration of drought	⇧	Low confidence on a global scale Likely changes in some regions	Low confidence
Intense tropical cyclone activity	⇧	Low confidence in long term changes Virtually certain in North Atlantic since 1970	Low confidence
Incidence and magnitude of extreme high sea level	⇧	Likely (since 1970)	Likely

Why does it matter?

Extreme weather events make headlines in Nebraska and around the world because of their potential to cause injuries and death, destroy infrastructure and ecological habitats, impact many economic activities, and degrade water and air quality. Disasters half a world away can affect economies and cause a disruption in the supply and transport of products from overseas suppliers or to overseas markets.

Evidence from U.S. Records

Climate change varies across the globe, and how it manifests itself over the coming decades will trigger differing impacts in every region. The nature and extent of these impacts and associated vulnerability depends on the amount of change that has occurred and will likely occur and the ability of citizens to respond and adapt. This section highlights the observed changes in climate for the United States.

Temperature

U.S. annually averaged temperature has increased by 1.3°F to 1.9°F since 1895 (Walsh et al., 2014). Consistent with global changes, this increase is not constant over space or time (Figure 3.3). Most of this warming has occurred since the 1970s, with the most recent decade being the warmest on record. Temperature increases since the 1970s range from 1°F to 1.5°F over much of the United States, with the exception of the southeast which experienced a slight cooling of -.5° to a slight warming of .5°F.

Precipitation

As a whole, precipitation amounts in the United States have increased, although the increases vary regionally and some areas have experienced less precipitation. Analyses show that since 1900 the annually averaged precipitation for the nation has increased by approximately 5% (Walsh et al., 2014). Again, important differences are apparent, both temporally and spatially (Figure 3.4). For most locations, these increases have occurred in the latter part of the record, reflecting the dryness associated with the droughts of the 1930s and 1950s. The largest increases are in the northern Great Plains, Midwest and Northeast, while the largest decreases are in Hawaii and parts of the Southwest.

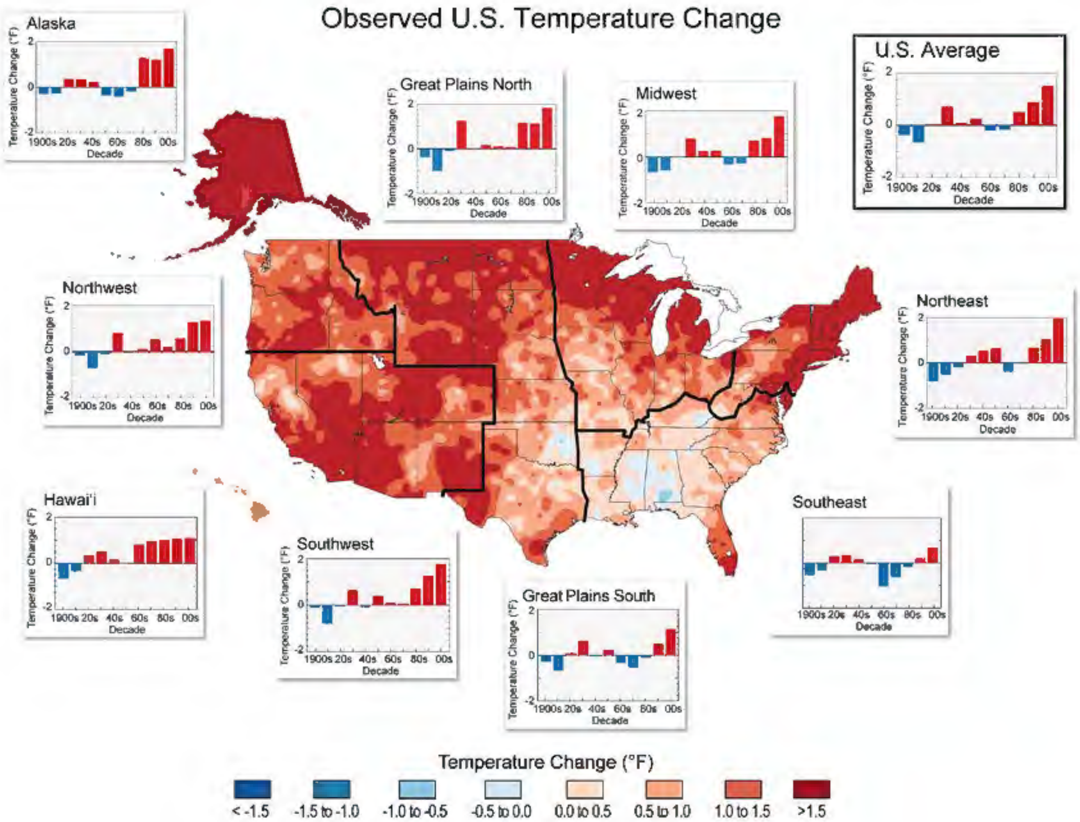


Figure 3.3. The colors on the map show temperature changes over the past 22 years (1991-2012) compared to the 1901-1960 average, and compared to the 1951-1980 average for Alaska and Hawaii. The bars on the graphs show the average temperature changes by decade for 1901-2012 (relative to the 1901-1960 average) for each region. The far right bar in each graph (2000s decade) includes 2011 and 2012. The period from 2001 to 2012 was warmer than any previous decade in every region. (Source: Walsh et al., 2014)

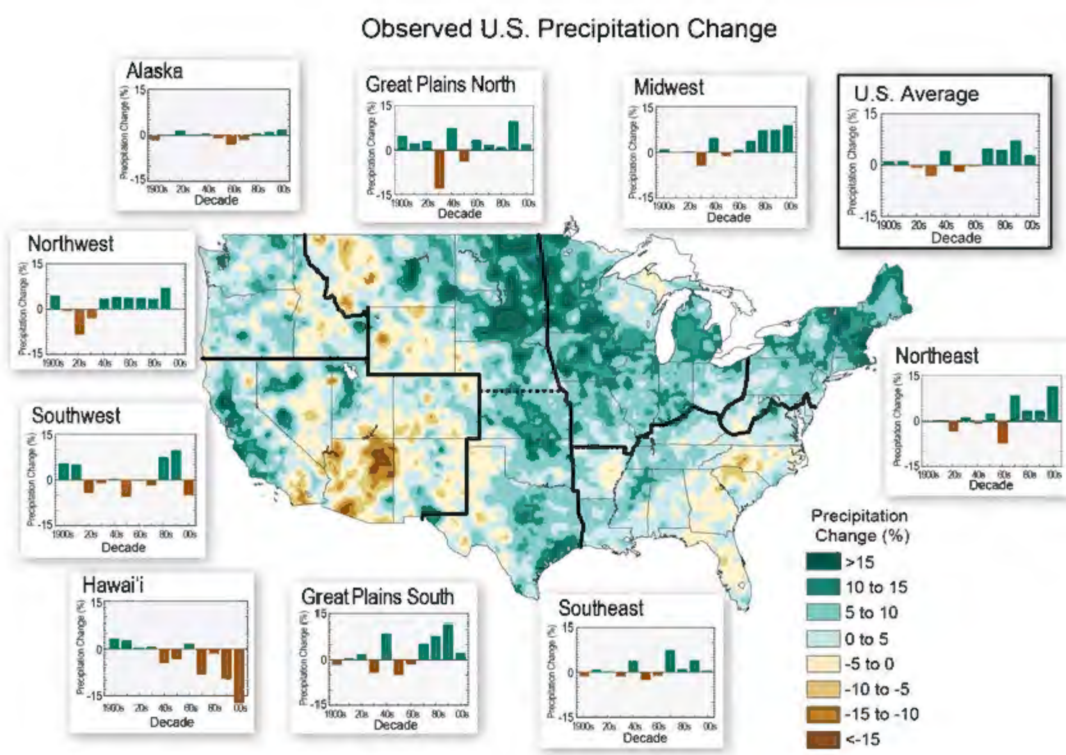


Figure 3.4. The colors on the map show annual total precipitation changes for 1991-2012 compared to the 1901-1960 average, and show wetter conditions in most areas. The bars on the graphs show average precipitation differences by decade for 1901-2012 (relative to the 1901-1960 average) for each region. The far right bar in each graph is for 2001-2012. (Source: Walsh et al., 2014)

Growing season

Because of the importance of agriculture to the U.S. economy, the National Climate Assessment (Walsh et al., 2014) has noted changes in the growing season as it corresponds to the number of frost-free days—that is, the number of days between the last frost of spring and the first killing frost of fall. The length of the frost-free season determines the types of indigenous and invasive vegetation and cultivated crops that can survive within a particular region. Research shows that the country as a whole has experienced an increase in the number of frost-free days (Figure 3.5). The spatial pattern of these increases is broadly consistent with the trends in annually averaged temperature. This pattern shows that increases in the frost-free season have been greater in the west than in the southeast, which shows overall cooling trends. Benefits associated with these increases include a longer growing season and a related increase in carbon dioxide uptake by vegetation. Disadvantages include the increased growth of undesirable plants and pests and an increased loss of moisture due to evapotranspiration, resulting in lower crop productivity and longer fire

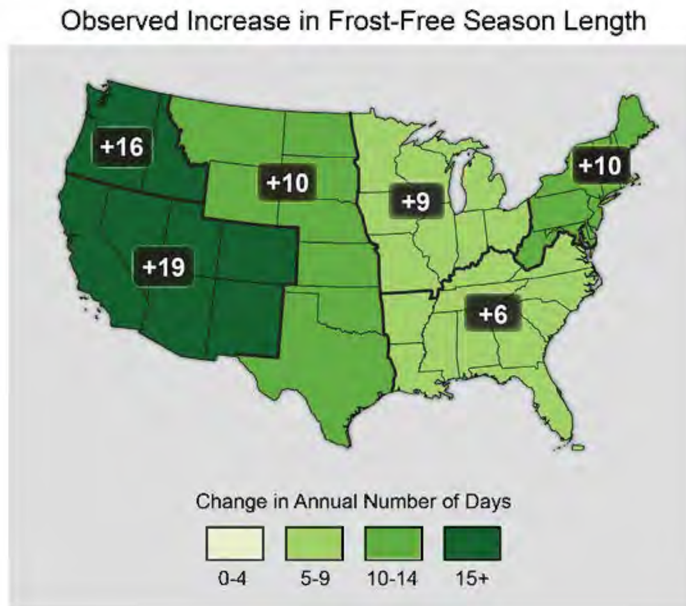


Figure 3.5. The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has increased in each U.S. region during 1991-2012 relative to 1901-1960. Increases in frost-free season length correspond to similar increases in growing season length. (Source: Walsh et al., 2014)

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Drought stricken dryland corn north of York, August 2006.

seasons. Whether or not the impacts are positive or negative will ultimately depend on moisture availability and soil quality, among other factors.

To put these changes in the length of the growing season in perspective, there has been a significant shift in plant hardiness zones in the United States over the past two decades. For Nebraska, the plant hardiness zones between 1990 and 2006 changed dramatically. In 1990, the state was divided, with the southern portion of the state in zone 5 and the northern half of the state in zone 4. By 2006, the entire state was in zone 5, with the exception of small portion of the state along the border with Kansas that was in zone 6 (Figure 3.6). In general, one could summarize by that for most of the Great Plains, including Nebraska, these zones have shifted by one full hardiness zone over the last 25 years. These changes in plant hardiness zones are having a profound effect on agriculture and ecosystems across the United States, even without considering changes in precipitation.

Extreme events

Since 1980, the United States has sustained more than 150 weather events with damages of $1 billion or more. Recent notable events include Hurricane Sandy in 2012, the heat wave and drought of 2011 and 2012, and the outbreak of tornadoes across the Midwest and Plains, which devastated Moore, Oklahoma, in 2013. Recovery from these extreme events, which normally requires a significant infusion of federal funding, is very expensive. As an example, the droughts of 2011 and 2012 led to federal expenditures of $62 billion (Weiss et al., 2013). During these same years, 25 severe storms, floods, droughts, heat waves, and wildfires occurred, with a combined total loss of $188 billion.

Across the country and around the world, people are asking whether these events are a consequence of a changing climate. To answer this question, eighteen international research teams examined the twelve events with impacts exceeding a billion dollars each that occurred in 2012 in various parts of the world (Peterson et al., 2013). Three of the events analyzed occurred in the United States. These events were the spring and summer heat wave of 2012, the extreme March 2012 warm anomaly over the eastern United States, and Hurricane Sandy. Of all the events analyzed by the research teams, it was concluded that anthropogenic

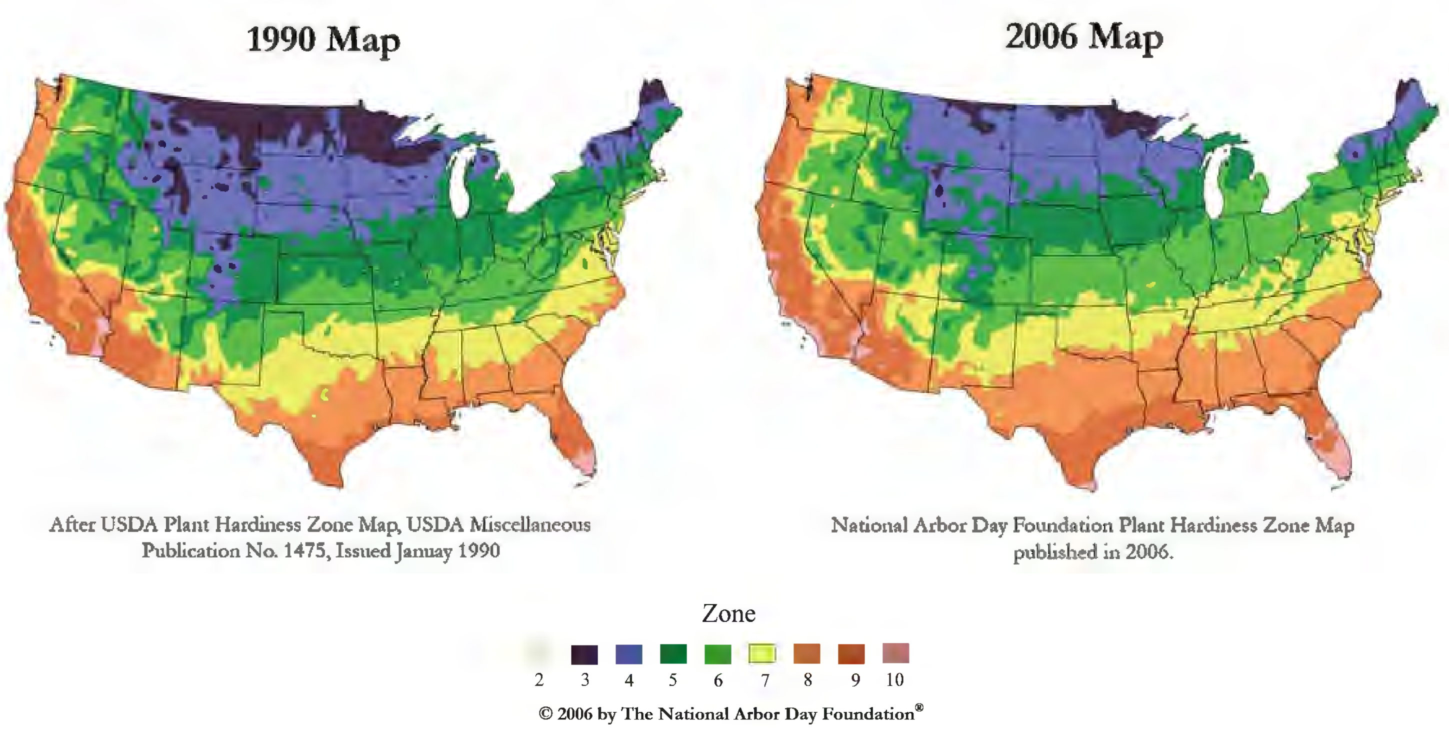


Figure 3.6. Differences between 1990 USDA hardiness zones and 2006 arborday.org hardiness zones. (Source: Adapted from Arbor Day Foundation, n.d.)

climate change was a contributing factor, although natural fluctuations played a significant role as well. Although the occurrence of the 2012 drought perhaps can be explained by natural variability, human-induced climate changed was found to be a factor in the magnitude of the warmth in the corresponding heat wave. Another recent study found that although the increased temperatures associated with global warming might not cause droughts, they were likely to lead to quicker onset and greater intensity of droughts (Trenberth et al., 2014). Likewise, climate change related sea-level rise also nearly doubled the probability that flooding from Hurricane Sandy would occur.

The influence of climate change is not limited to these few events. The observational evidence shows trends in a number of temperature extremes, and these trends are projected to continue (Table 3.2). The amount of rain falling in heavy precipitation events has also increased. The largest increases have occurred in the Northeast and Midwest (Figure 3.7) and are generally associated with increases in flood magnitude (Walsh et al., 2014).

Table 3.2. Observed changes in temperature extremes across the U.S. over the period 1895 to 2012. Table created with information from the 2014 National Climate Assessment. (Walsh et al., 2014)

Phenomenon	Direction of trend
Number of warm spells/heat waves	⇧
Number of cold spells/cold waves	⬇
Daytime high temperatures	⇧
Nighttime low temperatures	⇧
Number of record high monthly temperatures	⇧
Number of record low monthly temperatures	⬇

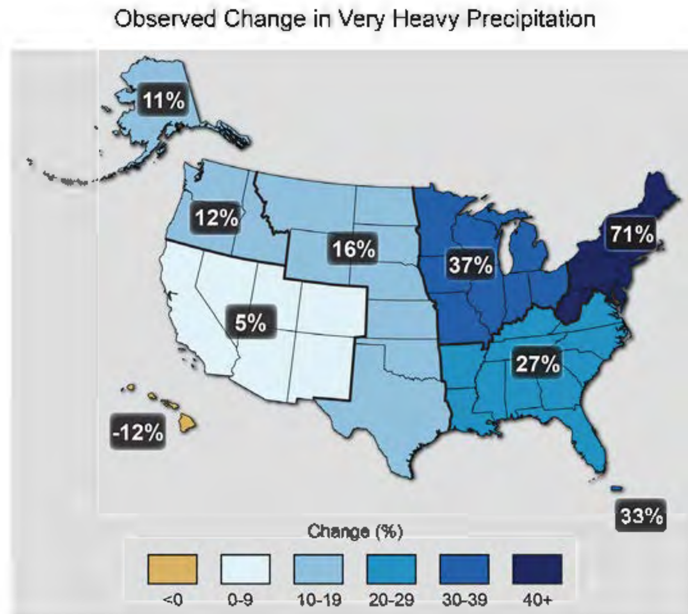


Figure 3.7. Percent changes in the annual amount of precipitation falling in very heavy events, defined as the heaviest 1% of all daily events from 1901 to 2012 for each region. The far right bar is for 2001-2012. In recent decades there have been increases nationally, with the largest increases in the Northeast, Great Plains, Midwest, and Southeast. Changes are compared to the 1901-1960 average for all regions except Alaska and Hawaii, which are relative to the 1951-1980 average. (Source: Walsh et al., 2014)

Winter storms are also showing an increase in frequency and intensity since 1950 as well as a poleward shift in the storm tracks (Walsh et al., 2014). Trends in snowfall amounts show regional variability, with general decreases in the south and west and increases in the northern Great Plains and Great Lakes regions. Snow cover has decreased, in part, because of warmer temperatures causing earlier melt and increasing the amount of precipitation that falls as rain rather than snow. Likewise, warmer temperatures have also reduced U.S. lake ice and glaciers.

Although the financial impacts from thunderstorms and tornadoes have increased, scientists are not yet able to separate suspected climate change related factors from societal contributions to this trend. However, the increase in the number of extreme severe weather events is cause for significant concern.

Historical Climate Trends for Nebraska, 1895-Present

Nebraska is located in the heart of the U.S. Great Plains, positioned near the center of the North American continent. For the climate, it means that we do not feel the moderating influence of the ocean, but rather experience a highly continental climate with cold winters, hot summers, and high variability from year to year. The most notable climate feature in Nebraska is the moisture gradient from east to west, in which the eastern half is classified as humid while the west is classified as semiarid. As such, annual precipitation totals range from 36 inches in the southeast to less than 15 inches in the northwest.

Systematic weather observations began in Nebraska (and across the United States) in the middle to late 1800s. Early in the observational record, there were about 100 observing locations around the state, though many of those stations were short-lived. Currently, more than 280 sites observe the weather conditions. For this report, we considered only those stations that are deemed the highest quality and most homogeneous, and have long periods of record (1895 to present). By looking at a long history of these observations, we are able to ascertain variability and changes in climate over time.

Nebraska's average annual temperatures range from about 55°F in the far southeast to about 46°F in the northern panhandle. Over the last century, there has been much fluctuation in temperature for the annual average, and notable warm periods such as the 1930s and 2000s stand out in the record. For many locations, and for the state as a whole, 2012 was the warmest year the state has experienced over the instrumental period of record. Nebraska has experienced an overall warming of about 1°F since 1895. When this is separated into daytime highs and nighttime lows, the trend in low temperatures is greater than the trend in high temperatures, both of which show an overall warming. Seasonally, the trends show some interesting differences. Winter (Dec, Jan, Feb) and spring (Mar, Apr, May) show the greatest warming of 2.0°F and 1.8°F, respectively, while summer has a 1.0°F warming and fall has no discernable trend in temperature. These trends are consistent with the changes experienced across the Plains states, which show a general warming that is highest in winter and spring and a greater warming for the nighttime lows than the daytime highs.

As with annual average temperature, precipitation varies strongly from year to year in Nebraska. Notable dry periods of the 1930s and 1950s are prominent in the historical record, though the driest year to date has been 2012. Unlike temperature, however, there is no discernable trend in mean annual precipitation in Nebraska. Seasonally, the trends in precipitation show the greatest amount of change in spring, with a general increase across the state. Summer is trending toward slightly less precipitation, while fall and winter show essentially no trend.

A significant portion of land in Nebraska is utilized for agricultural production. As such, the length of the growing season and changes over time are particularly important. The length of the frost-free season in Nebraska has increased, anywhere from 5 to 25 days and on average by more than one week since 1895.

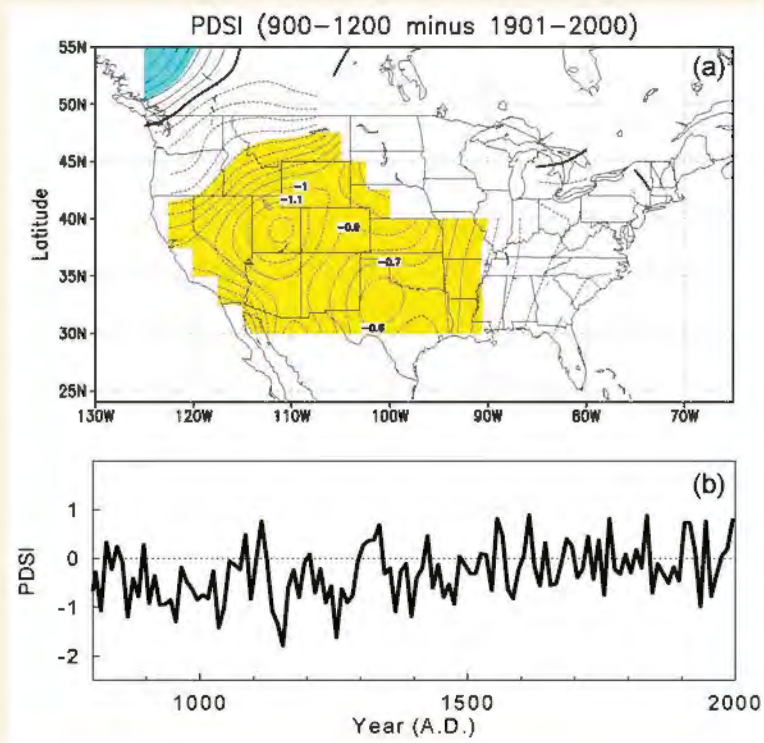
Extreme events such as hot and cold days can have significant impacts on human and animal health and energy demands. Extremely warm days, such as those with high temperatures greater than 100°F, have decreased over time by 5 days on average across the state. Even though summer has shown a general warming, the number of extreme hot days has decreased. Scientific studies show similar trends for other areas of the Plains and Midwest where agriculture is predominant. The prevalence of irrigation in the region is thought to strongly influence this trend by providing added moisture to the environment. During winter, the extreme cold days have shown a decreasing trend, with fewer events over time. Days with temperatures colder than 0°F have decreased by about 4 days since the late 1800s.

BOX 3.1.
Past Climate in the Great Plains: Focus on Megadroughts

A dominant feature of the climate of the Great Plains over the past 2,000 years is the occurrence of prolonged periods of drought, termed *megadroughts*. This prehistoric climate history has been reconstructed with the assistance of so-called proxy indicators such as tree ring count and width, the deposits contained within lake sediments, and the composition and occurrence of sand dunes.

The proxy record clearly indicates that megadroughts affected North America especially during the medieval times (MT) that lasted from approximately A.D. 900 to 1300. (*Megadroughts* refers to periods of drought much more prolonged than what has occurred during the historic record.) Tree-ring records in particular show that droughts were especially frequent and persistent throughout much of the western United States (30–50°N, 90–125°W) during the MT. These droughts usually lasted for decades—indeed, sometimes for most of a given century (see figure below).

The overall dry conditions during the MT are also recorded by terrestrial wind-borne deposits and alluvial stratigraphic evidence from the waxing and waning of lakes, as well as chemical and salinity reconstructions from lake sediments. These episodic but long-term (relative to the present) droughts had tremendous impacts on ecosystems and past civilizations. For example, the incidence of wildfires during the MT was very high along the Pacific coast. The prolonged droughts drove Native American populations into abandoning their homes and migrating to areas with more reliable water supplies. In the Great Plains, the grassland cover of the sand dunes was destroyed, and the dunes became mobilized, indicating drought conditions much more severe than those of the twentieth century (Sridhar et al., 2006). In summary, multiple lines of evidence suggest that during the MT, drought was the dominant feature of climate rather than the exception.



(a) Difference in tree ring reconstructed PDSI for 900-1200AD minus 1901-2000. Negative values indicate the regions were drier in MT. Shadings indicate the differences are significant at 95% confidence level by two-tailed Student t-test. (b) Regional averaged PDSI for the western United States (30-50°N, 90-125°W). To retain the low frequency variations in PDSI, only the 10-year average values of PDSI were shown. (Source: Adapted from Feng et al., 2008. Used with permission of the authors)

Emerging evidence suggests that during the earlier period from 4,000 years to 2,000 years before present, an opposite pattern occurred—that is, a tendency for wetter conditions. One key conclusion based on lake diatom records (Schmieder et al., 2011) is that the frequency of hydrological variation appears different in the last 2,000 years, relative to the previous 2,000 years. In particular, the records suggest more frequent oscillations during the last 2,000 years versus longer duration dry and wet spells before that. This seems to fit well with the eolian (wind-borne) records—and is a pattern also seen in recent high resolution (subdecadal) records from the northern Plains (Hobbs et al., 2011).

Summarizing, given the importance of already scarce water resources in Nebraska, the fact that we may have been in an unusually wet period during the past 150 years may well exacerbate any overall drying and loss of water due to climate change in coming decades. Though it appears wetter periods may have occurred several thousand years ago, this should not be considered a potential relief, or an indication that we are currently entering such a period. The past record clearly indicates that this is a region with scarce water resources. Sometimes there is a bit more water, all too often a bit less. All of the climate model projections suggest that this will likely get worse in the future. These projected changes in water availability for Nebraska must be incorporated in planning efforts by state agencies, local communities, Natural Resource Districts, and others.

CHAPTER 4

UNDERSTANDING THE CAUSES OF OBSERVED CHANGES IN CLIMATE

What Is Causing Changes in the Earth's Climate?

Evidence that human activities influence the global climate system continues to accumulate because of an increased understanding of the climate system and its response to natural and anthropogenic factors, more and better observations, and improved climate models. In fact, in the latest assessment report, the IPCC now states with 95% confidence that human influence is the main cause of the observed warming in the atmosphere and oceans and other indicators of climate change and that continued emissions of greenhouse gases (GHGs) will cause further warming and changes in the components of the climate system (IPCC, 2013).

The Laws of Physics Provide the Foundation of Climate Science

Climate change science involves the study of a multitude of processes that affect the climate system. Some of these processes can be investigated and understood through observational evidence and the use of controlled laboratory experiments, while others are more difficult to investigate because of the complexity of the interactions and the openness of the climate system. In the latter case, scientists must use conceptual, statistical, and numerical models to advance knowledge.

What determines global climate?

Radiation balance primer

The earth's surface receives, on average, 340 W m^{-2} (watts per square meter) of radiation from the sun (solar radiation), the primary source of energy driving the earth's climate system (Figure 4.1). Of this amount, approximately 240 W m^{-2} is absorbed by the earth. To maintain a balance, the earth must radiate the same amount of energy back to space (terrestrial radiation). Any imbalance between the absorbed solar radiation and the emitted terrestrial radiation would result in a change of the earth's temperature as net energy was added or lost. Because the radiant energy emitted by any object is proportional to its temperature, the earth

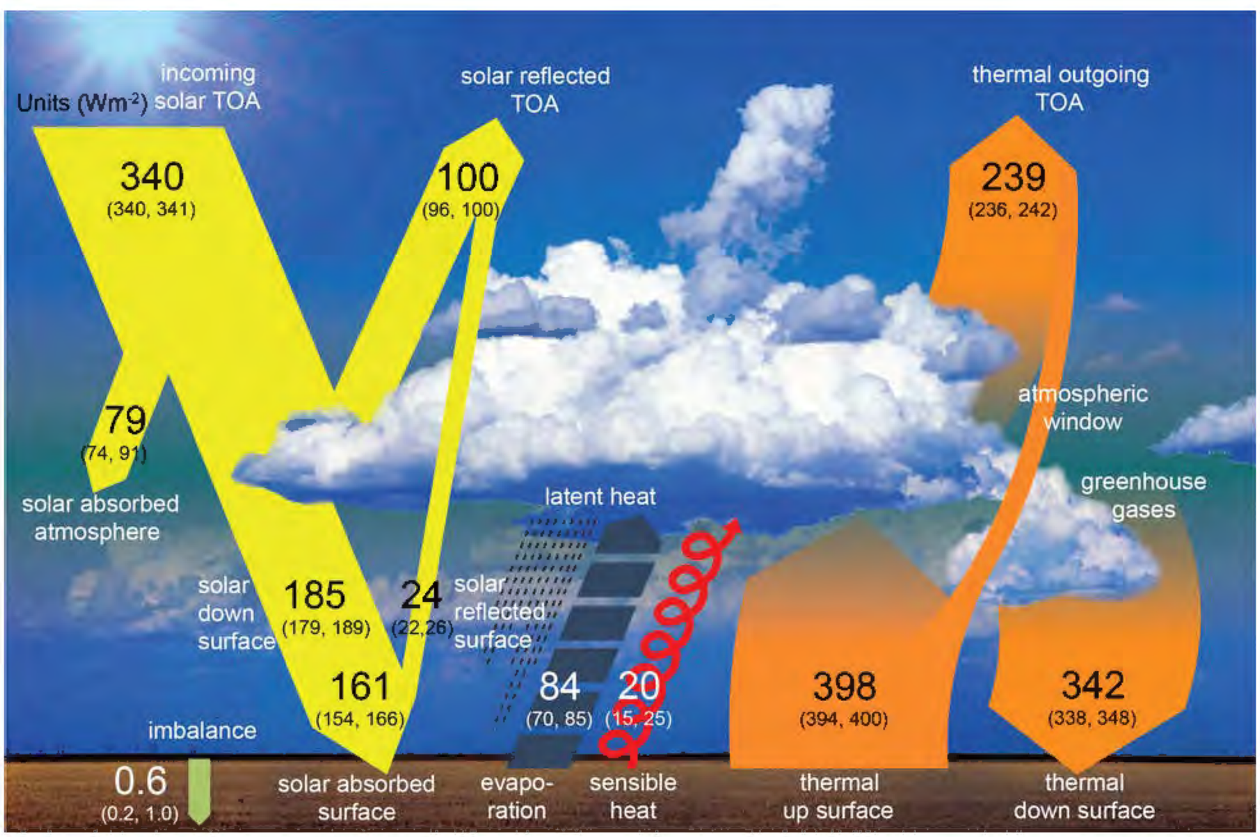


Figure 4.1. Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m^{-2}, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Source: Hartmann et al., 2013)

should have an average temperature of about -1°F. This is considerably lower than the observed average surface air temperature of approximately 57°F. What is the cause of this difference? It is the atmosphere or, more specifically, the GHGs in our atmosphere. The earth's atmosphere is a mixture of gases (Figure 4.2), primarily nitrogen (N_2), oxygen (O_2), and argon (Ar), which make up more than 99.9% of the atmosphere (excluding water vapor) and which, for the most part, do not interact with solar or terrestrial radiation. The remaining 0.1% of the atmosphere includes several gases that interact strongly with terrestrial radiation. These include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs). In addition, water vapor (H_2O), which is highly variable in space and time, is a potent greenhouse gas. These GHGs absorb much of the terrestrial radiation emitted from the earth's surface, heating the atmosphere. The atmosphere, in turn, emits terrestrial radiation—both upward into space to largely balance the absorbed solar radiation and downward to warm the surface and lower atmosphere where we live.

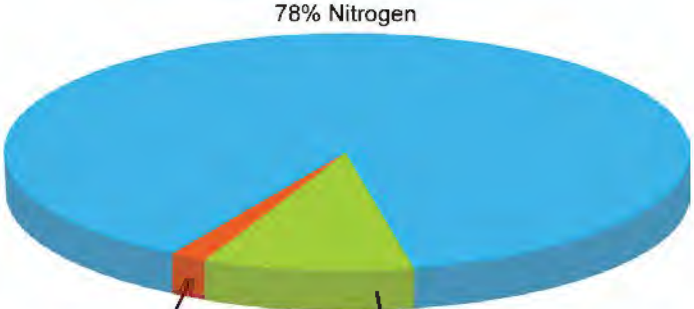


Figure 4.2. Composition of the earth's atmosphere.

The effects of these GHGs was first demonstrated by John Tyndall, a British physicist, in laboratory experiments in 1859, and the magnitude of the greenhouse effect was first quantified by Swedish physicist Svante Arrhenius in 1896. These GHGs cause the average surface air temperature to be higher than if they were absent, and increases in the concentrations of these GHGs will unquestionably result in increased global average temperature—in the absence of climate feedbacks. Climate feedbacks can be negative (acting in the opposite direction to the initial disturbance) or positive (acting to amplify the disturbance). Because evaporation from the oceans increases as temperature rises, the amount of water vapor in the atmosphere will increase. Water vapor is the largest contributor to the natural greenhouse effect, and an increase in atmospheric water vapor will act to enhance the greenhouse effect, further increasing the temperature—a strong positive feedback. Increases in certain type of clouds may constitute a negative feedback by reflecting more solar radiation; however, other types of clouds may result in greater absorption of terrestrial radiation and provide an additional positive feedback. Overall, the net effect of feedbacks in the climate system is positive, enhancing the direct effect of increasing atmospheric CO_2 on global temperature.

Because of the increased concentrations of GHGs due to human activities, there is currently a small, but significant, positive net imbalance of approximately 0.6 W m^{-2} between the absorbed solar radiation and the terrestrial radiation emitted to space. This imbalance, which has been increasing since the beginning of the Industrial Revolution, is the driving force behind the observed increase in global temperature since that time. A doubling of the CO_2 concentration from pre-industrial levels will lead to an imbalance of about 4 W m^{-2}.

Mechanisms that can change the radiation balance

Natural/External Forcing

Superimposed on changes in the average radiation balance and average global temperature are climate variations at many different time scales. The largest climate variation experienced in many parts of the world, including Nebraska, is the seasonal cycle: winter, spring, summer, and autumn. The cause of this climate variation is the tilt of the earth's axis of rotation relative to its orbit around the sun. During winter in the Northern Hemisphere, the North Pole is tilted away from the sun,

Box 4.1.
Water Vapor as a Potent Greenhouse Gas

Water vapor is a strong greenhouse gas; in fact, it is more potent than CO_2. As global temperature rises because of the increased concentration of CO_2, increased evaporation results in more water vapor in the atmosphere. This further enhances the greenhouse effect, resulting in additional warming. This positive feedback approximately doubles the effect of CO_2 alone.

reducing daylight hours and decreasing the intensity of the sun's rays, causing less solar radiation to heat that hemisphere and resulting in lower temperatures. In the summer, the opposite occurs: more daylight hours, higher intensity solar radiation, more heating, and higher temperatures. The seasons in the Southern Hemisphere are reversed on the calendar because when the North Pole is tilted toward the sun, the South Pole must be tilted away from the sun. Over tens of thousands of years, the earth's orbit about the sun and its tilt undergo variations. Although these variations have little effect on the average radiation received over the entire earth, they do cause considerable changes in the seasonal cycle and the latitudinal variation in solar radiation receipt. These changes in orbital forcing are most significant at high latitudes and are considered to play an important role in the waxing and waning of ice ages over geologic time. Over the past few thousand years and continuing into the future, orbital forcing alone would be expected to cause a global cooling, rather than the observed warming.

Energy output from the sun changes over time, as well. An (approximately) 11-year periodicity in the number of sunspots has been observed over centuries and, since the advent of satellite observations, measurements have also found an 11-year periodicity in solar output of about 0.1%, but no long-term trend has been observed. Estimates of solar output from longer records of sunspots also show small fluctuations of varying length but do not reveal any longer-term trend (Figure 4.3d).

Volcanic eruptions can have a major impact on the climate by injecting ash and gases into the atmosphere. Although these impacts can be quite large, they last, at most, for only a few years and result in a temporary cooling of the climate—the opposite of the observed trend. Moreover, volcanic eruptions are highly episodic and show no trend over historical time (Figure 4.3c). These external forcing mechanisms—orbital, solar, and volcanic—contribute to the natural variability observed in the earth's climate system, but cannot account for the observed trend in global atmospheric temperature since the middle of the nineteenth century.

Anthropogenic Forcing

Before the large-scale use of fossil fuels for energy (which started during the Industrial Revolution), the concentrations of the major GHGs (CO_2, methane, nitrous oxide) were remarkably constant during human history (Figure 4.3). Since then, concentrations of these gases have risen—slowly at first, then more rapidly since the middle of the twentieth century—and contributed about 3.0 W m^{-2} of total radiative forcing to the earth's climate system. Burning of fossil fuels (and other human

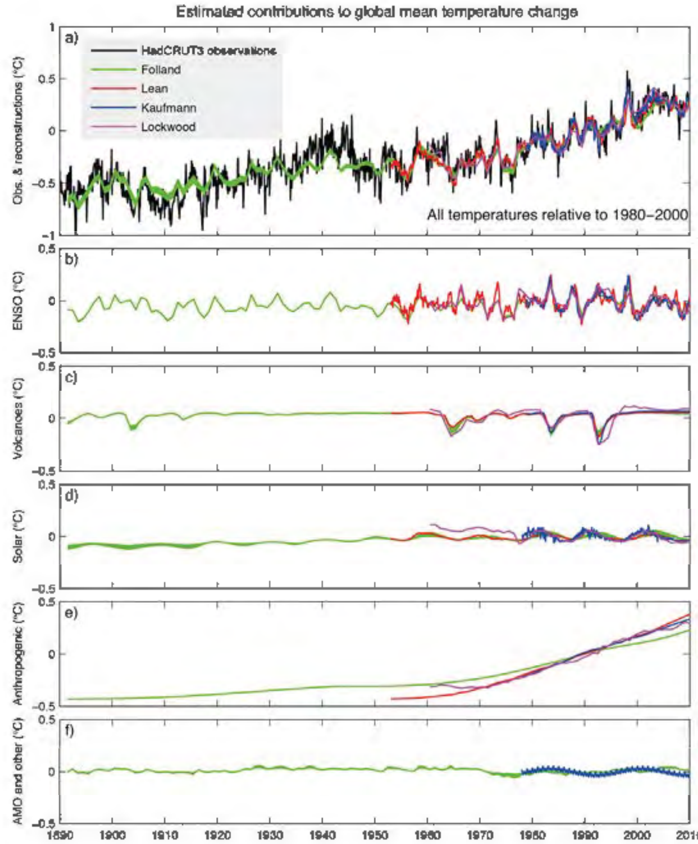


Figure 4.3. (Top) The variations of the observed global mean surface temperature (GMST) anomaly from Hadley Centre/ Climatic Research Unit gridded surface temperature dataset version 3 (HadCRUT3, black line) and the best multivariate fits using the method of Lean (red line), Lockwood (pink line), Folland (green line), and Kaufmann (blue line). (Below) The contributions to the fit from (a) El Niño-Southern Oscillation (ENSO), (b) volcanoes, (c) solar forcing, (d) anthropogenic forcing, and (e) other factors (Atlantic Multi-decadal Oscillation [AMO] for Folland and a 17.5-year cycle, semi-annual oscillation [SAO], and Arctic Oscillation [AO] from Lean). (Source: Bindoff et al., 2013)

activities) also results in emissions of aerosols into the atmosphere. Although there is much uncertainty about their climate impact, aerosols are thought to have a net negative radiative forcing of about -0.82 W m^{-2}— reducing the net total radiative forcing (once additional minor forcing factors are included) of anthropogenic changes to the atmosphere to 2.36 W m^{-2}.

GHGs are well-mixed gases, meaning that they stay in the atmosphere long enough to become relatively uniformly distributed in the atmosphere, and measurements from a few base locations are considered representative of global values. Once scientists began taking precise, accurate measurements of CO_2 in the earth's atmosphere at Mauna

Loa Observatory in Hawaii in the 1950s, scientists had additional evidence of the relationship of GHGs to temperature.

The concentration of CO_2 and other GHGs in the atmosphere is shown in Figure 4.4 for their common period of record. These figures show that CO_2, methane, and nitrous oxide have all increased, while fluorinated gases have decreased (as a result of an international treaty phasing out these substances). When scientists extend these records back in time using gas bubbles trapped in ice cores, it is evident that concentrations of the GHGs (CO_2, methane and nitrous oxide) have significantly exceeded pre-industrial levels (by about 40%, 150%, and 20%, respectively) and are substantially higher than they have been in the last 600,000 years. Furthermore, scientists can say with very high confidence that the rate of increase of these gases is unprecedented in the last 22,000 years. When comparing the concentrations of these gases to temperature, scientists found strong evidence of the influence of CO_2 on temperature.

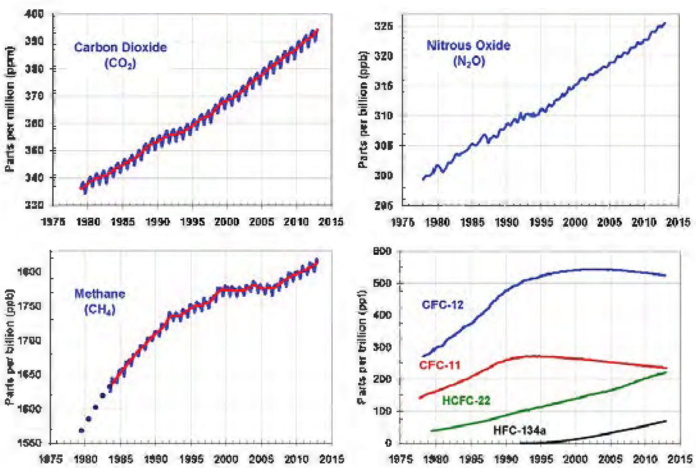


Figure 4.4. Global average abundances of the major well-mixed long-lived greenhouse gases—carbon dioxide, methane, nitrous oxide, CFC-12, and CFC-11—from the NOAA global air sampling network are plotted since the beginning of 1979. These gases account for about 96% of the direct radiative forcing by long-lived greenhouse gases since 1750. The remaining 4% is contributed by an assortment of 15 minor halogenated gases including HCFC-22 and HFC-134a. (Source: NOAA, 2014)

Because many GHGs such as CO_2, methane, and nitrous oxide can persist in the atmosphere for decades to centuries, warming of the earth's atmosphere will continue into the future even if emissions are reduced.

Understanding the physics of GHGs and their role in warming the atmosphere does not alone explain the changes in the climate systems. Scientists must take other factors, such as changes in land use, into account. Humans have been changing land surfaces for centuries through activities such as deforestation, afforestation, farming, reservoir creation, urbanization, and wetland destruction. These alterations are also major drivers of climate change because they affect the flux of carbon, heat, and moisture between the surface and atmosphere (Mahmood et al., 2010). When the land is disturbed, stored CO_2 along with other GHGs such as methane and nitrous oxide are released to the atmosphere and contribute to warming. Disturbances to natural land cover can also cause erosion, soil degradation, and nutrient depletion, reducing the ability of plants to serve as a carbon sink and resulting in an increased amount of GHGs in the atmosphere. Estimates suggest that 42-68% of the earth's surface was changed by human activities between 1700 and 2000, and that land use changes represent 15-46% of total annual CO_2 emissions since the beginning of the industrial era (Myhre et al., 2013). The contribution of land use changes and human activities to warming of the earth's surface varies by region, but has been estimated to be as much as 0.9°F on a global scale (Matthews et al., 2014).

Improvements in Observational Capabilities Provide Enhanced Evidence

The number, types, and quality of environmental observations and scientific studies have increased dramatically since climate change theories were first developed in the late nineteenth century. Before that time, instrumental records are incomplete, as many parts of the world were not monitored. Major advances include the routine launch of weather balloons in the 1950s, which provided scientists with information about the atmosphere above the surface, and high accuracy measurements of atmospheric CO_2 concentrations, which allow scientists to separate fossil fuel emissions from those due to the atmosphere's natural carbon cycle. The addition of routine satellite observations in the late 1970s provided major advances in understanding the climate system by enabling scientists to quantify changes across space and time. Since the first photographs of the earth from space, satellite observations have become increasingly more sophisticated and now include quantitative measurements of temperature, precipitation, sea ice cover, concentrations of atmospheric gases, vegetation changes, radiation fluxes, and many other important elements. The launch of the Argo ocean observing system in 2000 provided, for the first time, continuous global-scale monitoring of the upper ocean's temperature, heat content, salinity, and velocity. The addition of each new observational system in recent years has greatly increased the number of observations by orders of magnitude, provided observations in places where, previously, no data existed, and played a key role in helping scientists monitor and understand the climate system.

Advances in Understanding Lead to Stronger Conclusions

Advances in climate science, as in all fields of science, are made following a process in which ideas are tested with evidence from the natural world. But unlike scientists in other disciplines, climatologists are unable to perform controlled laboratory experiments on the earth as a whole and then observe the results. Nonetheless, scientists have repeatedly developed, tested, and refined hypotheses of numerous aspects of the climate system. Observational evidence and climate models are critical to testing hypotheses. For example, the global cooling that was observed following the eruption of Mt. Pinatubo in 1991 enabled scientists to test and verify feedbacks within the climate system. In the 1970s, a few researchers published a theory of global cooling based upon an observed short-term temperature decrease in the 1940s very likely due to small reductions in sunlight and the cooling effect of increasing aerosol pollution (Peterson et al., 2008). This theory was not accepted as a scientific consensus because a large majority of research articles at that time predicted, supported, or provided evidence for warming. Instead, it was an idea that the media perpetuated, giving the illusion of a consensus, just as the media today portrays an equally divided view on current climate change conclusions, when, in fact, there is a clear

Box 4.2.
What is Scientific Concensus?

A scientific consensus represents the collective position, at any given time, of the community of scientists *specialized* in a field of study. This consensus is primarily achieved through the process of peer-review, a quality control mechanism for scientific research in which experts scrutinize the work of other scientists in the same field. A scientific consensus does NOT mean that all scientists are unanimous in their conclusions, nor does it imply proof. In fact, there is no such thing as final proven knowledge in any science. The heart of science is the testing of ideas against evidence from the natural world. As new studies are developed and new conclusions are reached, theories may change and, likewise, the scientific consensus may evolve.

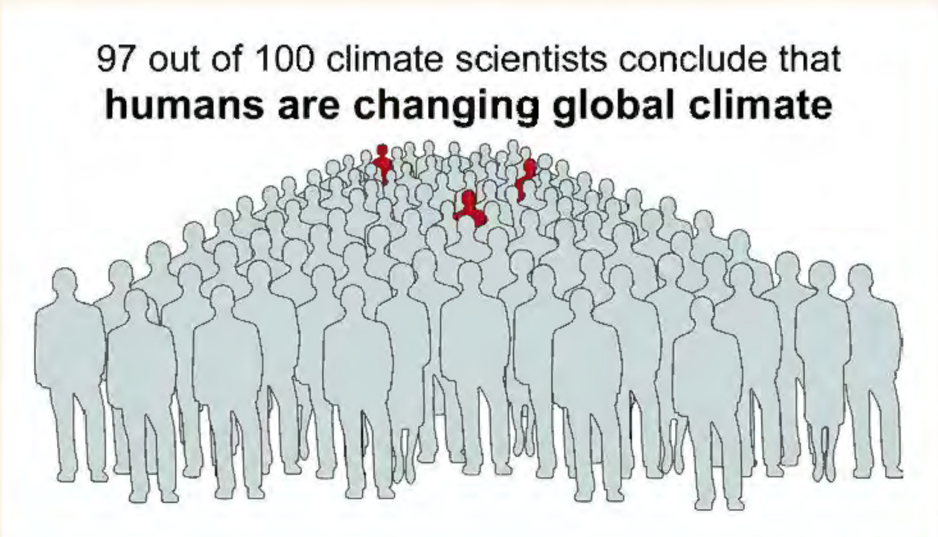


Illustration of the scientific consensus that 97 out of 100 actively publishing climate scientists agree with the overwhelming evidence that humans are causing global warming. (Source: Cook, 2014)

In the context of climate change, the consensus is that, based on the available evidence, 97% of *climate* scientists conclude that the earth's temperature is warming and that this increase is in part caused by the anthropogenic increase in greenhouse gases. The heat-trapping properties of carbon dioxide and other greenhouse gases – the backbone of climate change theory – are not in dispute. These were demonstrated in the mid-19th century and are *extremely* unlikely to change. Rather, as new data and analysis techniques become available, our understanding of the extent, magnitude, and impacts of climate change will increase and any relevant theories will be modified.

scientific consensus. Subsequent research and critique showed that the cooling predictions of the 1970s resulted from an overestimation of the effect of aerosol pollutants and an underestimation of the warming effect of CO_2.

Throughout history, a large body of scientific knowledge regarding climate change has developed through the self-correcting process of proposing ideas, testing hypotheses from multiple researchers, and scrutinizing findings through the peer-review process. In recent decades, the number of articles published per year in climate and atmospheric science journals has grown exponentially, representing considerable growth in our understanding of how the climate system works (Le Treut et al., 2007). The increasing sophistication of climate models in terms of the complexity and range of earth system processes demonstrates how much the state of knowledge has advanced (Figure 4.5). Scientists are now able to use climate models to simulate the climate of the past century and separate the human and natural factors that have contributed to the observed changes in temperature. The climate models are only able to reproduce the late twentieth century warming when human and natural factors are included (Figure 4.6) (Bindoff et al., 2013). In fact, when human factors are removed, climate models show that temperatures would have cooled in response to natural variations in volcanic eruptions and solar output.

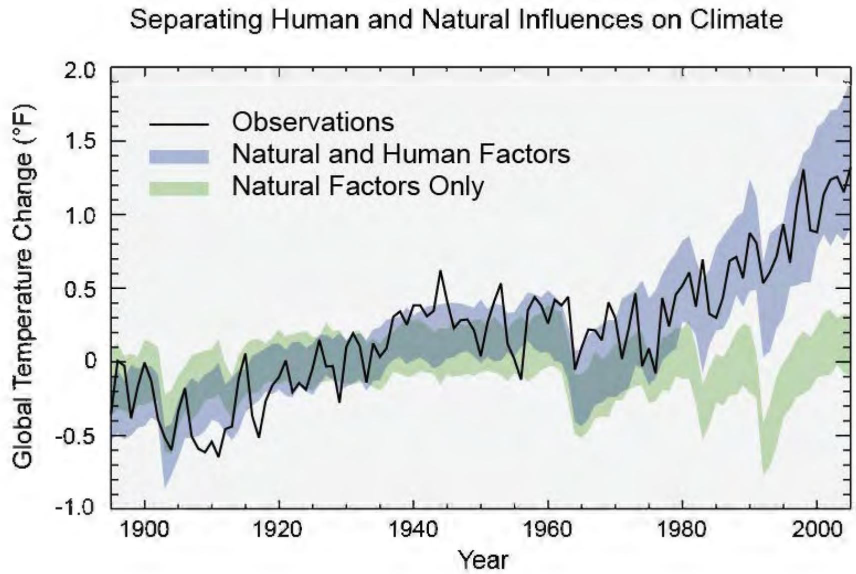


Figure 4.6. National Climate Assessment observed global average changes (black line), model simulations using only changes in natural factors (solar and volcanic) in green, and model simulations with the addition of human-induced emissions (blue). Climate changes since 1950 cannot be explained by natural factors or variability, and can only be explained by human factors. (Source: Walsh et al., 2014)

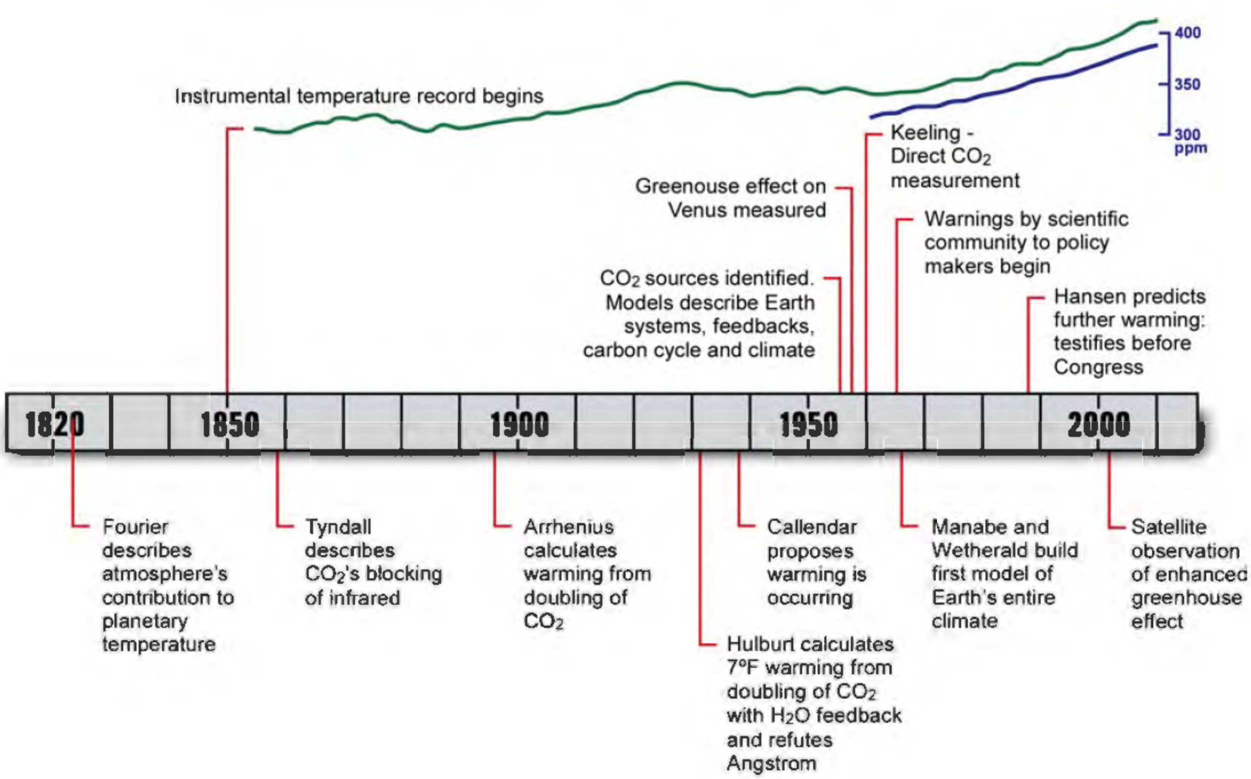


Figure 4.5. Milestones in climate science. (Source: Adapted from Mason, 2014)

CHAPTER 5

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

What Will the Future Climate Look Like?

Despite the growing number of countries with policies to reduce greenhouse gases, emissions continue to grow in many parts of the world (Figure 5.1). Even with the global economic crisis in 2007-2008, emissions grew more quickly between 2000 and 2010 than in each of the three previous decades (IPCC, 2014). Greenhouse gases accumulate over time and mix globally. Therefore, a concerted international effort is needed to effectively mitigate greenhouse gas emissions and address related climate change issues (IPCC, 2014). Until we, as a global society, can collectively agree upon such an effort, greenhouse gas concentrations will continue to increase, and thus the earth's average temperature will continue to increase. Because the climate is a complex system, scientists cannot say exactly how the climate will look in response to these increasing emissions from the burning of fossil fuels. However, scientists do know that by continuing to push greenhouse gases into the atmosphere, heat that would otherwise escape to space is retained, increasing the amount of energy in the earth system. Energy drives the weather, so the more greenhouse gases, the more weather and climate are affected. Natural influences on climate such as volcanic activity and changes in the sun's intensity will also play a role in determining what the future climate looks like.

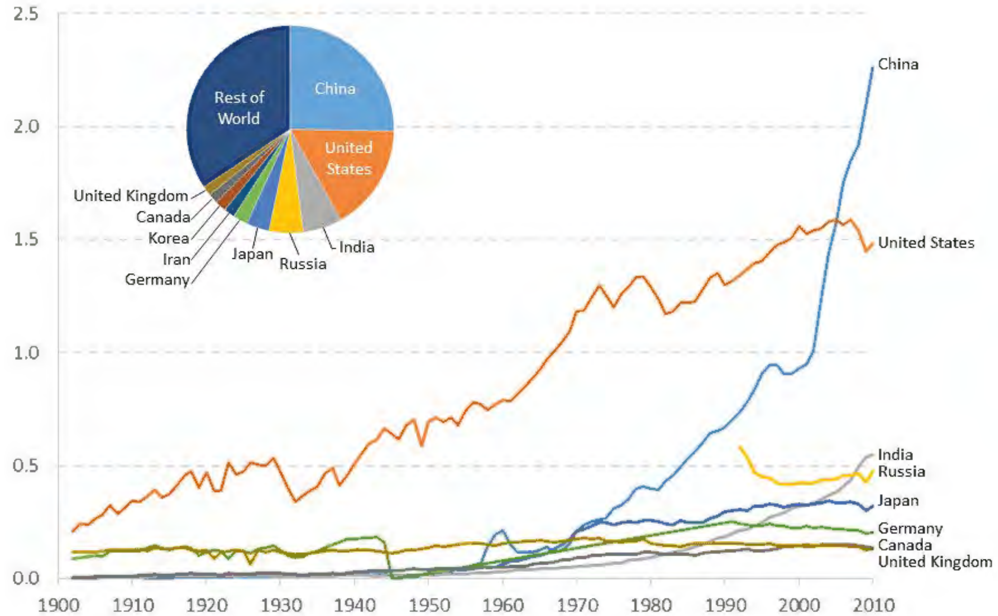
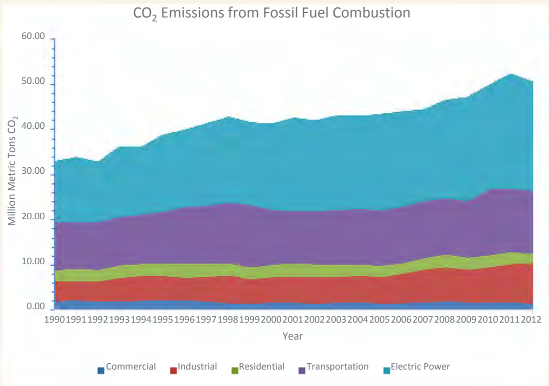


Figure 5.1. World Carbon Emissions for selected countries, 1900-2010 shown in billions of metric tons of Carbon. (Source: U.S. Department of Energy)

To provide the best estimate of future climate change, scientists use a pool of the world's most sophisticated global climate models to simulate what the future could

Box 5.1.
Nebraska Greenhouse Gas Emissions, 1990-2012, by sector

The figure in this box illustrates the trend of GHG emissions from fossil fuel combustion for Nebraska. All sectors show an upward trend for the period from 1990 to 2012. The sectors shown are commercial, industrial, residential, transportation, and electric power.



Nebraska CO_2 emissions from fossil fuel combustion, expressed in million metric tons CO_2. (Source: EPA, 2014) look like based on scenarios, or assumptions, of what greenhouse gas emissions, population growth, energy use, economic development, and technology use could look like in the future (Table 5.1). However, it is important to keep in mind that climate projections are subject to uncertainty, largely due to the uncertainty of future emissions, and that projected values of temperature, precipitation, and other variables could fall—either higher or lower—outside the range spanned by climate models. More information on climate models and how they work can be found in Chapter 6.

Table 5.1. Summary of the emission scenario characteristics used in the climate modeling community. (Adapted from Van Vuuren et al., 2011)

Climate model scenario	Scenario characteristics		Greenhouse gas scenario description used in this report
	Greenhouse Gas Emissions	Air Pollution	
RCP 2.6	Very low; aggressive reduction and sequestration	Medium-Low	Very Low
RCP 4.5	Low; mitigation efforts stabilize emissions by mid-century and then result in decreases thereafter	Medium	Low
RCP 6.0	Medium; emissions increase gradually and are stabilized near the end of the 21st century	Medium	Medium
RCP 8.5	High; emissions continue to increase through the end of the 21st century	Medium-High	High

Projections of the Global Climate

Temperature

Because projected atmospheric CO_2 concentrations for any realistic emission scenario (Figure 5.2) are not very different over the next decade or more, near-term climate projections differ little depending on the emissions scenario used. This means that over the next 10-20 years they give rise to similar magnitudes and spatial patterns of climate change. This is the same time period over which interannual to decadal scale variability is also important. It is over the remainder of the century that the effects of global warming will especially dominate. The global mean surface temperature for the next two decades will likely be 0.5-1.3°F higher than the 1986-2005 average. Large seasonal variations in the changes are apparent, with most of the warming occurring over the Northern Hemisphere landmasses during winter. As the century progresses, the CO_2 concentrations of the various emission scenarios diverge, as do the projected temperature changes. The temperature increase by the end of the century for the (unlikely) very low greenhouse gas emission scenario could range from 0.5 to 3.0°F; for the more likely high greenhouse gas emission scenarios, the increase could range from 4.7 to 8.6°F (Figure 5.3). Warming is expected to continue beyond 2100. In both the near- and far-term projections, the largest warming is expected to be in the Northern Hemisphere landmasses, with a distinct polar amplification. Projected values fall well outside of what is expected to occur due to natural variability.

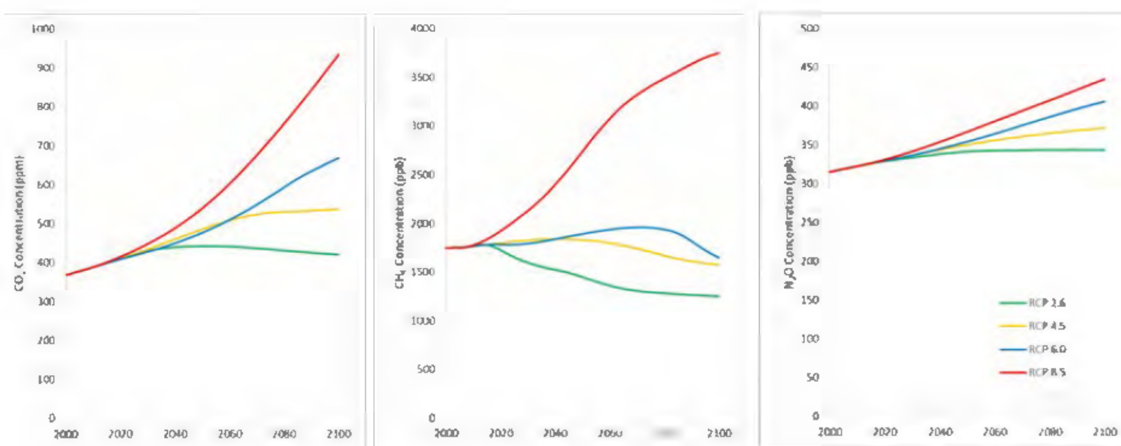
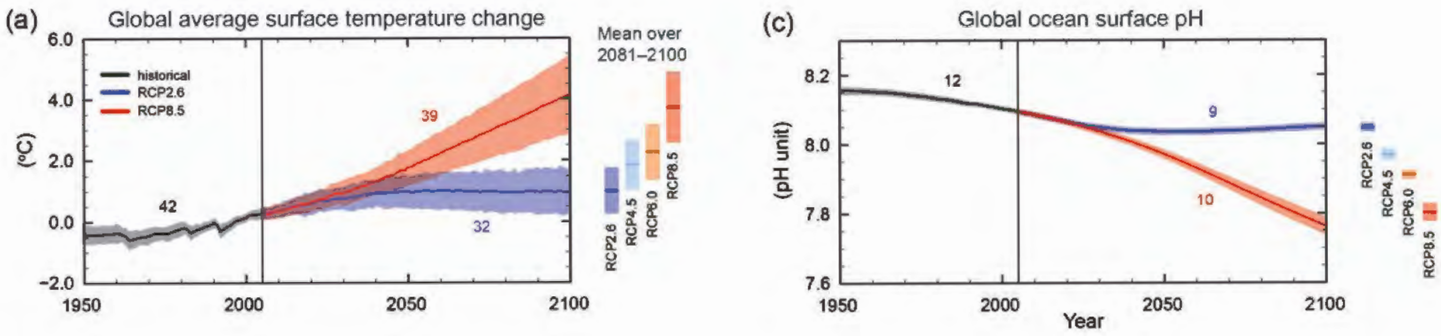


Figure 5.2. Projected trends in concentrations of greenhouse gases over the 21st century used in the IPCC Assessment Report AR5 scenarios. Left—CO2, middle—CH4, right—NO2. (Source: Adapted from van Vuuren et al., 2011)



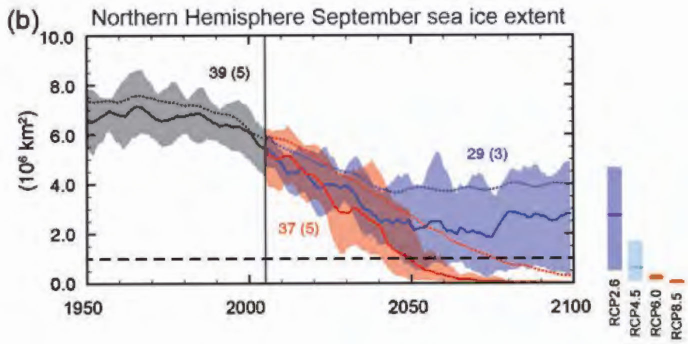
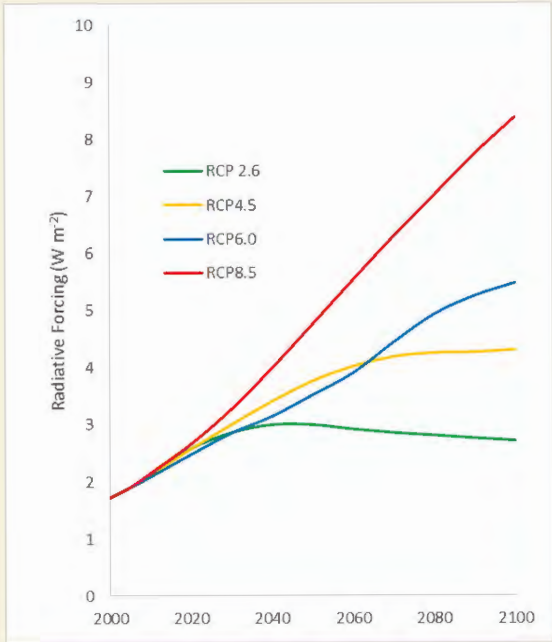


Figure 5.3. Simulated time series from 1950 to 2100 for global annual mean surface temperature, Northern Hemisphere September sea ice extent, and global mean ocean surface pH. (Figure source: IPCC, 2014)

Box 5.2.
Projecting Future Greenhouse Gas Concentrations

Before projections of global climate can be made, scientists must develop plausible projections of future concentrations of greenhouse gases, aerosols, and other constituents (excluding dust and nitrate aerosols) of the atmosphere that affect the absorption and emission of radiation. For the fifth IPCC Assessment Report (AR5) climate projections, four independently developed *Representative Concentration Pathways* (RCPs) were used. These are named according to the level of additional radiative forcing they would have in 2100, relative to the pre-industrial period (see figure in this box). These RCPs were chosen to represent the range of radiative forcing available in the scientific literature at the time of their selection and are not directly tied to any specific climate policy action (or absence thereof) or to particular socioeconomic futures. That being said, the Very Low pathway (RCP 2.6) would require substantial global decreases in greenhouse gas emissions almost immediately and continuing through the century (and beyond), while the High pathway (RCP 8.5) may turn out to be optimistic, given recent global emission trends.



Projected radiative forcing with RCPs.

Precipitation
Uncertainty is larger for precipitation than for temperature and, for regional and smaller scales, the magnitude of projected changes is small compared to natural variability. Evidence from modeling studies comparing observations with simulations of recent climate suggests that models may underestimate the magnitude of changes in precipitation (Kirtman et al., 2013). With these caveats in mind, agreement among modeling studies combined with understanding of the temperature-atmospheric moisture relationship leads scientists to conclude that it is virtually certain global mean precipitation will increase in the long term. As with the observed changes in precipitation (see Chapter 3), projected changes are expected to vary considerably across the globe and by season.

An increase in the annual amount of precipitation falling in very heavy events has been one of the trends observed throughout the Great Plains and Midwestern states.

Ken Dewey, University of Nebraska–Lincoln

In both the near- and long-term climate projections, the general pattern of change for the coming decades and extending to the end of the twenty-first century is that wet areas will become wetter and dry areas will become drier, with some regional and seasonal deviations (Kirtman et al., 2013). The largest increases are seen in the tropics and the Arctic and could exceed 30% and 50%, respectively. Changes in the tropics are seemingly driven by changes in atmospheric circulation that promote more tropical rainfall, while increases in the polar regions are driven by temperature increases, enabling more water to exist in the atmosphere and an enhanced transport of water vapor to higher latitudes. In the already dry subtropical regions, increased temperatures promote increases in evaporation, and changes in atmospheric circulation promote less rainfall and a potential expansion of desert regions. These changes are amplified when high greenhouse gas emission scenarios are used in modeling studies.

Snow and ice cover
Scientists have concluded that as the earth continues to warm, it is virtually certain that Northern Hemisphere sea ice, glaciers, ice caps, and seasonal snow cover will continue to decline in the coming decades and through the end of the twenty-first century (Kirtman et al., 2013). The models using high greenhouse gas emission scenarios project the largest declines, with nearly ice-free summers in the Arctic Ocean in a few decades, something that has not happened in at least the last 5,000 years (Funder et al., 2011; Kinnard et al., 2011).

Evidence also suggests that the rate of melt is likely to accelerate beyond the rapid, unprecedented declines that have already been observed in the last 30 years. At this time, there is not enough evidence to suggest that the Arctic might lose so much ice that its heat-reflecting properties are diminished to a point where the sea ice could not recover (Kirtman et al., 2013). Although studies indicate a reduction in Antarctic sea ice extent and volume in the future, confidence is low for these model projections because of the wide range of model responses and a general inability to reproduce recent sea ice trends and variability.

Snow cover extent changes in direct response to projected increased temperatures and in response to more variable changes in precipitation. Temperature changes reduce the amount of time that snow remains on the ground and affect the fraction of precipitation that falls as snow rather than rain. Given the consistency among model studies, scientists conclude that it is virtually certain that Northern Hemisphere snow cover extent will decrease in the future (Kirtman et al., 2013). Depending on the greenhouse gas emission scenario used, this decrease could be as high as 35%.

Oceans

Globally averaged ocean temperatures are very likely to continue increasing through the end of the twenty-first century (Kirtman et al., 2013). Surface warming estimates range from about 1°F for very low greenhouse gas emission scenarios to 3.5°F for high emission scenarios. Regional variations caused by ocean circulation and surface temperature heating are apparent, with the strongest surface warming occurring in the tropical and Northern Hemisphere subtropical regions. Because of the large heat capacity and slow response of the ocean, it may take many centuries for the deep ocean to come into equilibrium with greenhouse gas induced warming, signifying a long-term commitment to warming even after (or if) greenhouse gases emissions are reduced.

Global mean sea level is also projected to continue rising during the twenty-first century in all CO_2 emission scenarios (IPCC, 2013). It is also very likely the rate of rise will exceed the rate that was observed during 1971-2010. Contributing factors to these projections are the melting of land ice and thermal expansion of the oceans due to ocean warming (Church et al., 2013). Water expands slightly as it warms. But "slightly" in an ocean with a mean depth of 6,000 feet can still mean several feet of sea level rise. Regional sea level changes may differ from the global average because of ocean dynamics, sea floor movements, and water mass redistribution. However, by the end of the twenty-first century it is very likely that sea level will rise in more than 95% of the ocean area, with conservative estimates of 1 foot and 3 feet for very low and high greenhouse gas emission scenarios, respectively. Thermal expansion will cause sea level to continue to rise long after greenhouse gases are reduced.

As the ocean warms, it will continue to absorb anthropogenic greenhouse gas emissions for all model scenarios (IPCC, 2013), although at lower levels than what is presently occurring. Because warm oceans absorb less carbon than cold oceans, a larger proportion of emitted CO_2 will remain in the atmosphere. Furthermore, the continued absorption of CO_2 will result in a global increase in ocean acidification.

Extreme events

Consistency among modeling studies and scenarios leads scientists to conclude that it is virtually certain that the climate near the end of the twenty-first century will have more frequent hot temperature extremes over most land areas on daily and seasonal timescales. It is also very likely that heat waves will increase in frequency and intensity (Kirtman et al., 2013). Conversely, fewer cold days are projected, with a decrease in the number of frost days for all land masses in the Northern Hemisphere. Scientists predict that it is likely that heavy precipitation events will increase in frequency, intensity, and amount in response to warmer temperatures. Additionally, El Niño is expected (with high confidence) to remain the dominant mode of climate variability, and associated precipitation variability is expected to intensify, though specific regional responses may vary. The projections of other extreme events tend to have greater regional variation. A summary of the future manifestation of other extreme events can be found in Table 3.2.

Ken Dewey, University of Nebraska–Lincoln

Building foundations from the former town of Lemoyne, submerged by Lake McConaughy, reappear in 2006 as the water level drops to record low levels.

Projections of U.S. Changes in Climate

Regional climate models are essential tools for projecting the impacts of climate change on natural resources and society because these models incorporate higher detail of terrain, differing soil and vegetation characteristics, and smaller-scale atmospheric processes. Although regional models cannot reduce the uncertainty inherent in global climate projections, they can reduce the bias because of their higher resolution.

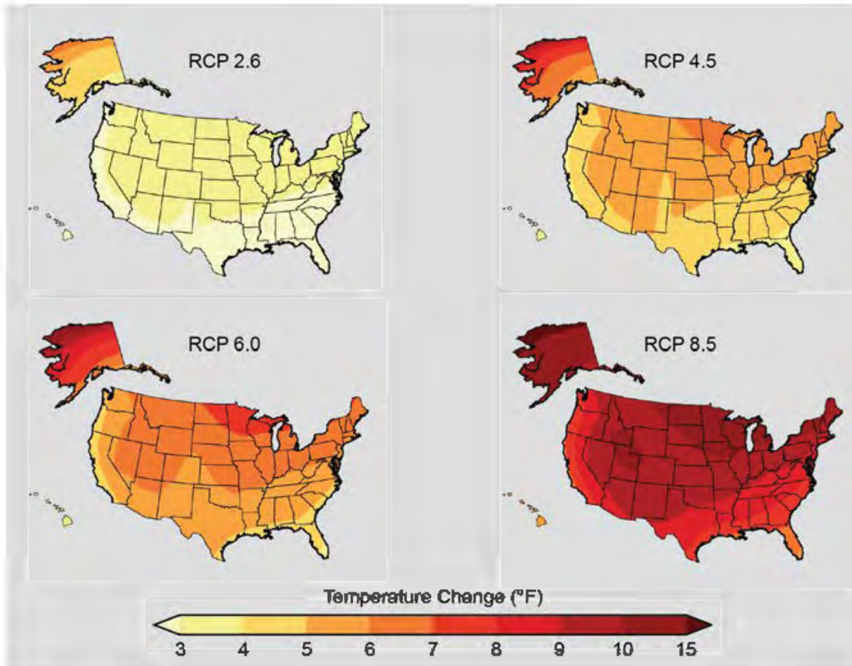


Figure 5.4. The largest uncertainty in projecting climate change beyond the next few decades is the level of heat-trapping gas emissions. The most recent model projections (CMIP5) take into account a wider range of options with regard to human behavior, including a lower scenario than has been considered before (RCP 2.6). This scenario assumes rapid reductions in emissions—more than 70% cuts from current levels by 2050 and further large decreases by 2100—and the corresponding smaller amount of warming. On the higher end, the scenarios include one that assumes continued increases in emissions (RCP 8.5) and the corresponding greater amount of warming. Also shown are temperature changes for the intermediate scenarios RCP 4.5 (which is most similar to B1) and RCP 6.0 (which is most similar to A1B). Projections show change in average temperature in the later part of this century (2071-2099) relative to the late part of last century (1970-1999). (Source: Walsh, 2014)

Temperature

Under all scenarios, the latest climate models project warming across the entire United States, with the magnitude dependent upon the future emissions of greenhouse gases and the amount of particle pollution in the atmosphere. Low-emission scenarios, or those that assume aggressive reductions in greenhouse gas emissions, predict a warming of around 2.5-3°F by the end of the century for the contiguous United States and as high as 7°F for parts of Alaska. Conversely, high-emission scenarios, or those that assume continued increases in greenhouse gas emissions, predict a warming of around 7-15°F by the end of the century for the contiguous United States (Figure 5.4) and more than 15°F for parts of Alaska (Walsh et al., 2014).

Precipitation

Like temperature, projected precipitation changes are dependent upon the greenhouse gas emission scenario used by the climate model (Walsh et al., 2014). In winter and spring, the high emission scenario shows increases on the order of 10-30% across the northern part of the country and reductions of 10-30% in parts of the Southwest (Figure 5.5). Less precipitation is predicted across much of the contiguous United States in the summer. Fall shows little to no change for most of the country. In general, the very low emission scenario shows similar patterns, but with smaller magnitudes than the high emission scenario. Additionally, decreases in precipitation are virtually nonexistent for this scenario.

Growing season

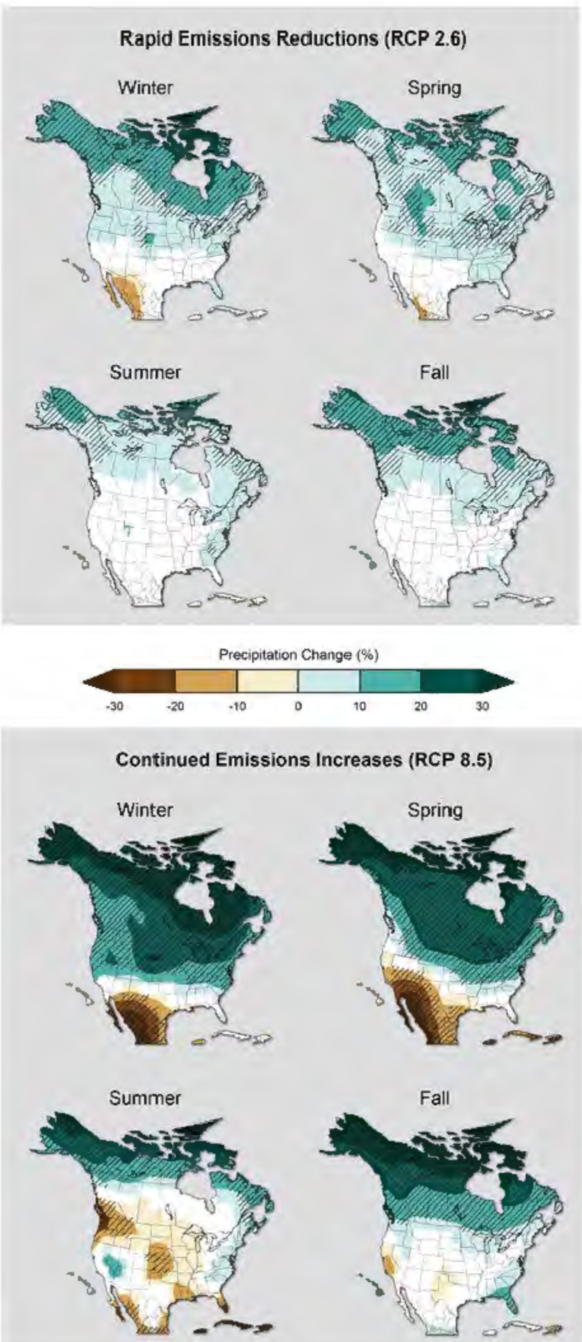
As average temperatures are projected to increase, the number of frost-free days will also increase (Figure 5.6) (Walsh et al., 2014). The projected changes are similar to those that have been observed (Figure 3.3) in recent decades, with the largest increases in projected frost-free days expected to occur in the western United States. These increases correspond to an increase in the growing season of at least a month to more than two months, depending on the emission scenario used by the climate model.

Based on projected temperature changes, the changes in plant hardiness zones shown in Figure 3.6 will continue to shift northward. Over the next 30 years, plant hardiness zone 6 will encompass the southern half of Nebraska.

Extreme events

In response to a warming climate, many extreme events will also increase (Walsh et al., 2014). For example, the record-breaking temperature extremes of the last few decades are projected to continue increasing in magnitude and frequency through the end of the twenty-first century regardless of the emissions scenario chosen (Figure 5.7). Likewise, the average temperature of the coldest days will also increase. This is not to say that extreme cold events

Figure 5.5. Seasonal precipitation change for 2071-2099 (compared to 1970-1999) as projected by recent simulations that include a wider range of scenarios. The maps in the top panel (RCP 2.6) assume rapid reductions in emissions—more than 70% cuts from current levels by 2050—and a corresponding much smaller amount of warming and far less precipitation change. The maps in the bottom panel (RCP 8.5) assume continued increases in emissions, with associated large increases in warming and major precipitation changes. These would include, for example, large reductions in spring precipitation in the Southwest and large increases in the Northeast and Midwest. Rapid emissions reductions would be required for the more modest changes shown by the maps in the top panel. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. (Source: Walsh, 2014)



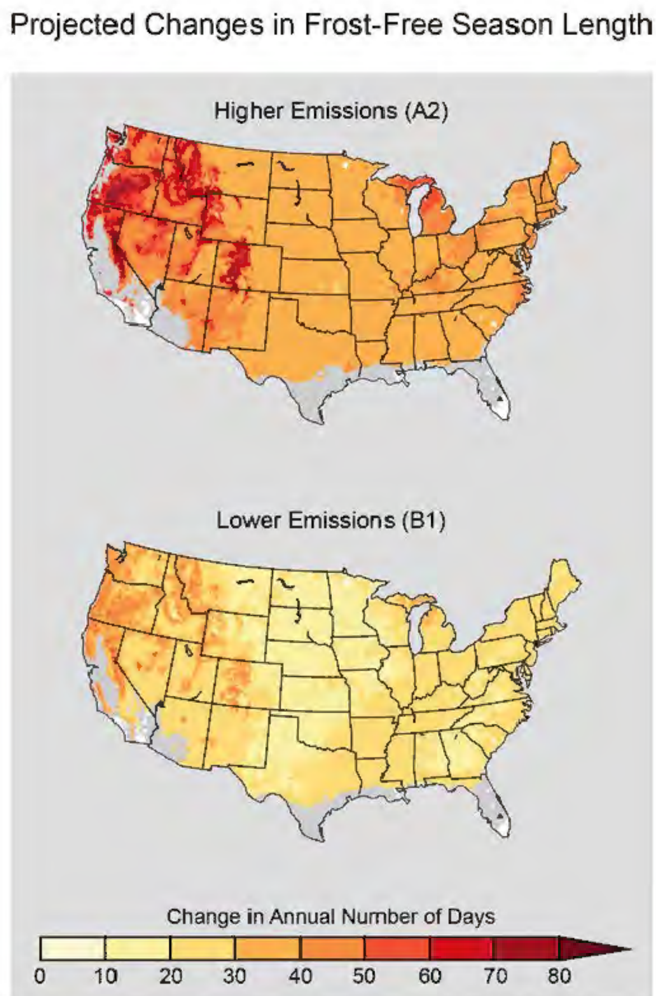


Figure 5.6. The maps show projected increases in frost-free season length for the last three decades of this century (2070-2099 as compared to 1971-2000) under two emissions scenarios, one in which heat-trapping gas emissions continue to grow (A2) and one in which emissions peak in 2050 (B1). Increases in the frost-free season correspond to similar increases in the growing season. White areas are projected to experience no freezes for 2070-2099, and gray areas are projected to experience more than 10 frost-free years during the same period. (Source: Walsh, 2014)

will not happen in the future, rather that the magnitude and likelihood of these events will decrease.

Projections of future climate changes also indicate a continued increasing trend in the number of heavy precipitation events, even for areas such as the Southwest that are projected to have overall decreases in precipitation (see Figure 3.6) (Walsh et al., 2014). These events could occur two to five times as often as they currently do, depending on future greenhouse gas emissions, and may result in increases in flash flooding.

Modeling studies show that drought, as indicated by the commonly used Palmer Drought Severity Index (PDSI),

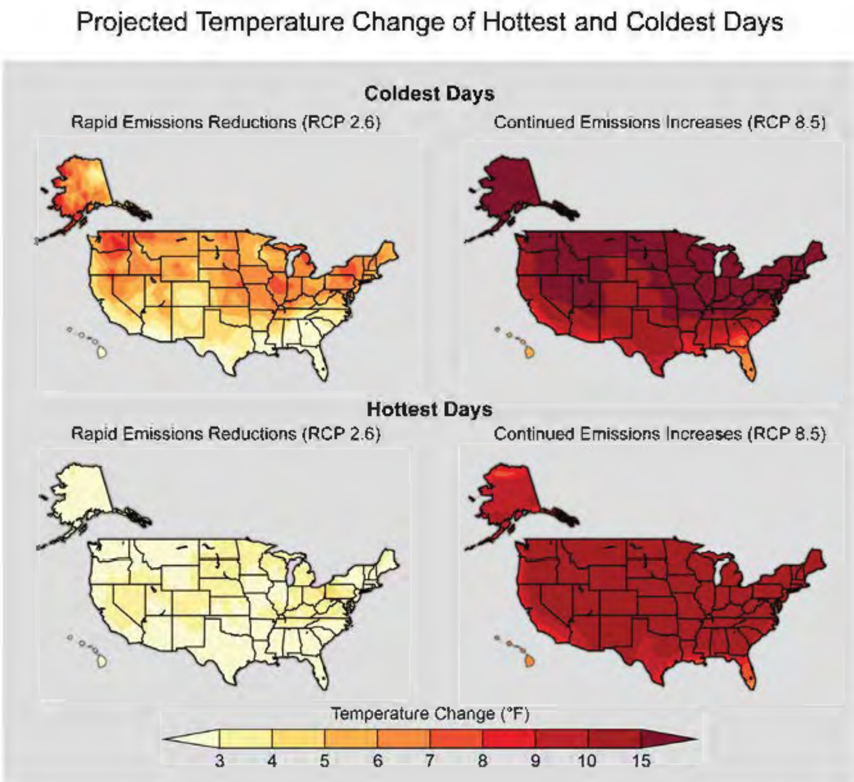


Figure 5.7. Change in surface air temperature at the end of this century (2081-2100) relative to the turn of the last century (1986-2005) on the coldest and hottest days under a scenario that assumes a rapid reduction in heat-trapping gases (RCP 2.6) and a scenario that assumes continued increases in these gases (RCP 8.5). This figure shows estimated changes in the average temperature of the hottest and coldest days in each 20-year period. In other words, the hottest days will get even hotter, and the coldest days will be less cold. (Source: Walsh, 2014)

is expected to increase in the future (Wehner et al., 2011). The PDSI uses temperature and precipitation data to estimate relative dryness. It is a standardized index that uses 0 as a normal and negative numbers to indicate increasing levels of drought severity. This analysis illustrates that a 4.5°F temperature increase could result in widespread drying over the central and western United States in the latter half of the twenty-first century. As a result, severe drought could become the new climate normal for these regions.

As temperatures increase, changes in other extreme events such as hurricanes, thunderstorms, and winter storms would also be expected to occur (Walsh et al., 2014). The impact of climate change on these phenomena is an active area of research and, for the most part, has greater uncertainty, as models do not always agree on the type or amount of change. With that said, climate models project a slight decrease in the overall number of hurricanes, but an increase in the strongest hurricanes. Rainfall rates within hurricanes are also expected to increase, which would result in increased inland flooding. The frequency of severe thunderstorms (those causing large hail, strong winds, and tornadoes) may also increase as favorable conditions for storm development become more common (Walsh et al., 2014). Finally, conclusions about future trends in winter storm frequency and intensity do not yet show consistent results.

Projections of Great Plains and Nebraska Climate

The Great Plains is a region with a highly variable climate on multiple time scales. Average annual precipitation diminishes rapidly from east to west, and interannual variability of precipitation is one of the region's defining characteristics. The region frequently experiences a wide range of weather and climate hazards such as tornadoes, droughts, floods, and other severe weather events that result in significant economic losses and stresses to a fragile ecosystem. Climate change will further exacerbate those stresses and increase economic losses in the future.

The National Climate Assessment (NCA) report (2014) includes a chapter on the Great Plains region, and the chapter authors identified five key messages for the region.

1. Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.

2. Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices.

3. Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.

4. Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events

occurring within an already highly variable climate system.

5. The magnitude of expected changes will exceed those experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.

Nebraska climate projections

Projected changes in Nebraska's climate are largely derived from the chapter for the Great Plains region in the NCA report (2014). As noted above, these projected changes in climate are based on the consensus of multiple climate models for both low and high emissions scenarios through the remainder of this century. Given the lack of global agreements to date on emission reductions, the higher emissions scenarios would seem to be the "most likely" for future changes in climate for the state.

Temperature

1. A rapid increase in average temperatures occurred from 1991 to 2012, compared to 1901 to 1960 for the northern plains states. Average temperatures have increased at a less rapid rate for the southern plains states over the past two decades.

2. Projected changes in temperature for Nebraska range from 4°F to 5°F (low emission scenarios) to 8°F to 9°F (high emission scenarios) by the last quarter of the twenty-first century (2071-2099). This range is based on our current understanding of the climate system under a variety of future emissions scenarios. The range of temperature projections emphasizes the fact that the largest uncertainty in projecting climate change beyond the next few decades is the level of heat-trapping gas emissions that will continue to be emitted into the atmosphere.

3. Under both the lower and higher emissions scenarios, the projected number of high temperature stress days over 100°F is expected to increase substantially. This increase for the Great Plains ranges from a doubling of the number of days (over the current average number of days) for the northern states to a quadrupling of the number of days in the extreme south. For Nebraska specifically, the projected changes are for high temperature stress days to increase to 13-16 additional days for the lower emissions scenario and 22-25 days for the higher emissions scenario. The current average number of days exceeding 100°F, based on the 1980-2010 normals, is 2.1 days/year for Omaha, 4.6 days/year for Lincoln, 3.5 days/year for Grand Island, 10.9 days/year for McCook, and 5.3 days/year for Scottsbluff. This increase for Nebraska in the number of high temperature stress days would equate to experiencing typical summer temperatures by mid-century (2041-2070) equivalent to those experienced during the 2012 drought and heat wave (Figures 5.8 and 5.9). For example, in 2012, the number of

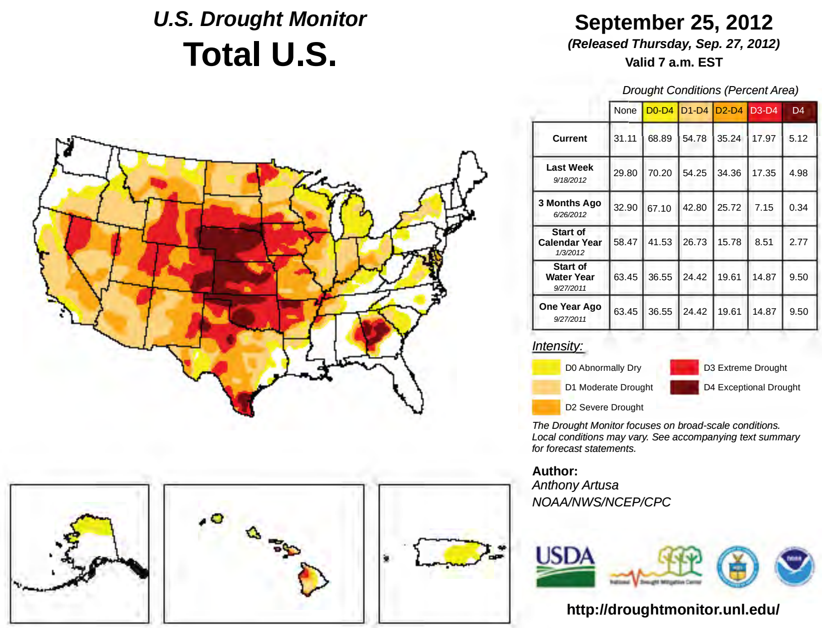


Figure 5.8. U.S. Drought Monitor in September 2012. (Source: National Drought Mitigation Center, 2014)

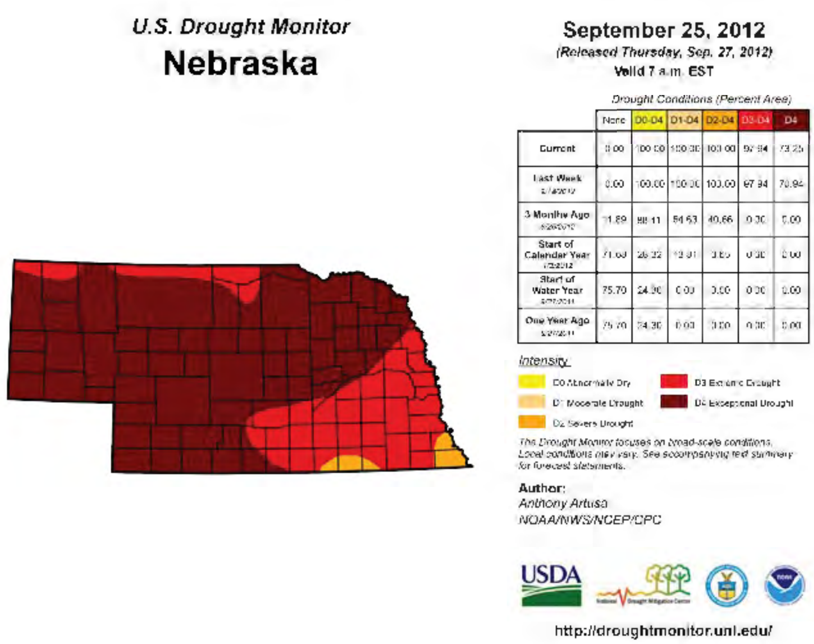


Figure 5.9. U.S. Drought Monitor for Nebraska in September 2012. (Source: National Drought Mitigation Center, 2014)

days that exceeded 100°F ranged from 10-21 days in eastern Nebraska to 21-37 days in western and southwestern Nebraska. In other words, temperatures during the summer by mid-century would, on average, be comparable to those experienced during the summer of 2012. The effect of these higher temperatures on evaporative demand and human health would be significant.

4. The number of warm nights, defined as the number of nights with the minimum temperature remaining above 80°F for the southern Plains states and above 60°F for the northern Plains states, is expected to increase dramatically. For Nebraska, the number of warm nights is expected to increase to an additional 20-25 nights for the lower emissions scenario and 25-40 nights for the higher emissions scenario.

5. The length of the frost-free season has increased significantly since 1991, when compared to the 1901-1960 average. This increase is between one and two weeks for the Great Plains overall. This trend has been confirmed for Nebraska. It is likely that the length of the frost-free season will continue to increase in the region, perhaps by an additional two weeks by mid-century.

Precipitation

1. Current trends for increased annual precipitation in the northern Great Plains are projected to become even more pronounced, while the southern Great Plains will continue to become drier by mid-century and later. The greatest increases for the northern Great Plains states so far have been in North and South Dakota, eastern Montana, and most of eastern Nebraska.

2. Winter and spring precipitation is expected to increase in the more northern states, with little change in precipitation for these two seasons for Nebraska.

3. Projected changes in summer and fall precipitation are expected to be small in the Great Plains, with some possibility of reduced summer precipitation in the central Plains states.

4. The number of consecutive dry days for Nebraska, based on the average during the period of record, is projected to increase by 1-3 days under both the lower and higher emissions scenarios.

5. There has been a significant trend toward an increase in the percentage of average annual precipitation falling in heavy rainfall events for both the northern and southern Great Plains states, when compared to the average for 1958-2012. This trend is much stronger for the states in the Great Plains and other states to the east than for states in the western United States. A 16% increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 has been calculated for the Great Plains region.

Soil moisture

Projected changes in soil moisture for Nebraska are for a decrease of 1-5% for the lower emissions scenario and 5-10% for the higher emissions scenario to the end of the twenty-first century. These changes reflect the combined effect of increasing temperatures and projected changes in precipitation for the state.

Flood magnitude

River flood magnitudes have been increasing in the eastern portions of the northern Great Plains states, including Nebraska, reflecting the increasing trend for heavier precipitation events. This trend is expected to continue given projections for a continued increase in heavy precipitation events for the northern Great Plains and the Midwest.

Steve Ress, Nebraska Water Center

Mounds of sand from Missouri River flooding in 2011 are deposited at a city park in Decatur, Nebraska. A trend of increasing flood magnitudes has occurred in recent decades in eastern Nebraska.

Snow cover

A major concern for Nebraska and other central Great Plains states is the large projected reduction in snowpack in the central and northern Rocky Mountains. This is due to both a reduction in overall precipitation and warmer conditions, meaning more rain and less snow, even in winter. Flow in the Platte and Missouri rivers during the summer months critically depends on the slow release of water as the snowpack melts. Such flow could be greatly reduced in coming years.

Irrigation and other land use changes
Human activities local to Nebraska can also be important in terms of how they influence the local climate. In particular, the advent of large-scale irrigation in Nebraska since the 1960s has kept the summertime climate in Nebraska cooler and wetter than it otherwise would have been. However, if reduced water availability curtails irrigation in the state, then the microclimatic effects of irrigation will be lessened in the future.

The implications of the projected changes for various key sectors in Nebraska are discussed in detail in the commentaries provided by experts. It is clear from the discussion in the NCA report (2014) that the consequences of these projected changes will vary greatly through the Great Plains as well as for each of the states in the region. The consequences of these changes will be determined by the vulnerability or sensitivity of key sectors to the changes, as well as the ability of these sectors to adapt and the availability of adequate groundwater resources to buffer some of the changes. Expected changes in precipitation amounts for Nebraska and the central Plains states appear to range from a slight increase to little change. However, given the projected increases in seasonal temperatures and the increase in the number of high temperature stress days (>100°F), evapotranspiration rates and water demand will increase dramatically, with serious implications for agriculture, energy demand, urban water supply systems, ecosystems, human health, and other sectors.

Extreme events in the context of Nebraska's future climate

Nebraska's climate features extreme events such as droughts, heat waves, heavy precipitation events, tornadoes, severe storms, and winter storms. These events will continue to occur.

The projection is for an increase in the frequency and intensity of certain extreme weather and climate events that occur in Nebraska, particularly droughts and heat waves. There may be a small increase in heavy precipitation events and it is difficult to know what will happen to the frequency and intensity of tornadoes, severe storms, and winter storms.

Extreme events occurring in other locations around the world also have an impact on Nebraskans in terms of agricultural commodity prices and national security.

Droughts, heat waves, and other extreme events
Nebraskans frequently experience extreme weather and climate events in the form of droughts, floods, heat waves, winter storms, and severe storms and tornadoes. One potential consequence of climate change is a possible change in the frequency and severity of extreme weather and climate events. The overall expectation is that extremes will generally increase in the United States and around the world (Karl et al., 2008; NCA, 2014). In the United States, the National Climatic Data Center has been tracking the occurrence of extreme events in order to have a record of current trends and to see any changes in the frequencies of these events as they happen. Extreme events in Nebraska can have a significant impact on Nebraska's economy, and so being aware of how these might change in the future is an important consideration. In addition, given the connectedness of the global economy, particularly in relation to agriculture, understanding how changes in the frequency and/or severity of extreme events around the world might positively or negatively affect Nebraska is also important.

Drought.
Drought is a critical issue for Nebraska. This was demonstrated again clearly during 2012, which was the driest and hottest year for the state based on the climatological record going back to 1895 (see Figures 5.8 and 5.9). Droughts have been a regular feature of climate across the United States, and the 1930s Dust Bowl Drought is a classic example of how drought has affected the Great Plains. Indeed, the prehistoric record suggests that over the past two millennia, prolonged "megadroughts" were a dominant regional feature (see Box 3.1). At this time, the long-term climatological record does not show any trends in drought frequency or severity at a national perspective (Peterson et al., 2013b; NCDC, 2014). There has been some evidence of more frequent and severe droughts recently in the western (Peterson et al. 2013b) and southwestern (Overpeck, 2013) United States, respectively.

Looking ahead, however, the expectation is that drought frequency and severity in Nebraska will increase, particularly during the summer months, because of the combination of increasing temperatures and increased seasonal variability in precipitation that is likely to occur (Melillo et al., 2014). Higher temperatures increase the potential evapotranspiration that is directly related to increased surface heating (Trenberth et al., 2014). If moisture is available at the surface, both evaporation and actual evapotranspiration demand from vegetation would then increase, reducing available water resources unless precipitation can compensate for this increased atmospheric demand. This scenario

(Trenberth et al., 2014) could lead to a potential increase in drought frequency and severity. Therefore, even if precipitation amounts remain the same or slightly increase in the future for Nebraska, already vulnerable water resources across the state will be stressed even further by these increased temperatures.

Droughts impact Nebraska directly through the agricultural and energy sectors, municipal and private water supplies, and natural resources across the state. For agriculture, droughts cause soil moisture deficiencies, plant water stress, and reduced crop yields. Crop production is especially vulnerable to heat and water stress during the critical development stages. In addition, droughts increase the potential for pest infestations, weeds, and diseases, which work to reduce crop quality as well as crop quantity (GSA, 2007). Nebraska's livestock production is affected by droughts as the quantity and quality of available forage on rangelands and pastures are reduced (GSA, 2007). All producers face indirect impacts during droughts as well that can range from increased water and energy costs for irrigation to the economic impact on communities as the agricultural productivity within a region is diminished. Indeed, even the projected reduction in snowpack across the Rockies could have an impact on the timing and availability of surface irrigation water in some locations across the state (Pierce and Cayan, 2013; Garfin et al., 2014; Mote et al., 2014).

Nebraskans should note that droughts around the world affect them as well. An initial impact of droughts that occur elsewhere likely would be beneficial for agricultural exports and the demand for Nebraska products. But droughts also have a major impact on global food security around the world and, as a result, have been shown to play a role in regional instability and conflicts, such as in Syria, for example (Department of Defense, 2014; Gleick, 2014). If droughts do increase in frequency and severity in some parts of the world, as the research suggests, the result could have a major impacts on national security and Nebraskans.

Heat waves.
With the projected increase in global and regional temperatures, it makes sense that there would be an increase in heat wave events occurring around the world. Across the United States, the current observed ratio of record high maximum temperatures compared to record low minimum temperatures is approximately 2 to 1 (Peterson et al., 2013b). The recently released National Climate Assessment provides details of what the future might look like for Nebraska by 2050 (Shafer et al., 2014). One metric used to demonstrate the impact of temperature increases during the summer months was to determine the typical "hottest" seven days and "warmest" seven nights within a year for the 1971-2000 period, and then calculate how many more "hot" days and "warm" nights would occur during a summer around 2050. If Lincoln is used as an example, the number of hot days would increase by 13-22 days during a given summer (depending upon the scenario), and the number of warm nights would increase by 20-35 nights each summer.

Nebraska heat waves are already hazardous to livestock health, so the increased number of heat waves would definitely impact the livestock industry (see the Commentary by Terry Mader in Chapter 7 of this report). Consistently elevated nighttime temperatures can have a major impact on livestock. Heat waves also potentially impact human health as well, and there would likely be impacts to crops, especially during critical growth stages, and energy usage during these heat waves. Although irrigation serves as a buffer to water stress that may result from elevated temperatures and can reduce maximum temperature occurrence (see other commentaries on water and agriculture in Chapter 7 in this report), the increased atmospheric demand resulting from projected changes in temperatures will result in reduced recharge to aquifers and increased reliance on groundwater for irrigation. This has long-term implications for the viability of irrigated agriculture in Nebraska.

Heavy precipitation events.
One of the expected changes in extreme events is an increase in heavy precipitation events. In fact, an increase in the number of heavy rainfall events has already been seen across the midwestern and eastern United States (Peterson et al., 2013b). The projections from two model scenarios only show slight increases in heavy precipitation events across Nebraska by 2041-2070, with a more noticeable increase in these events expected across the northern Plains states (Shafer et al., 2014).

Winter storms, severe storms, and tornadoes.
For these extreme events, meaningful trends that are currently taking place across the country are difficult to identify (Kunkel et al., 2013). Likewise, there is considerable uncertainty about how projected changes in the climate will affect these events (NCA, 2014). Nebraskans should keep in mind, however, that tornadoes and severe storms will continue to be a normal feature for Nebraska. And they should also note that winter storms and their associated impacts will still occur across the state (Kunkel et al., 2013).

CHAPTER 6

UNDERSTANDING CLIMATE PROJECTIONS

Climate scientists are unable to conduct controlled experiments on how the earth's climate will change as fossil fuel combustion continues to increase the concentration of greenhouse gases in the atmosphere—after all, we have only one earth and the "experiment" is already underway. This does not mean that science has no tools that can be used to understand and quantify the projected impacts of humankind on our climate system. These tools include computer models—of which there are many, developed by climate science groups around the world—that utilize the fundamental laws of physics, fluid dynamics, chemistry, and thermodynamics, together with standard mathematical methods, to project future states of the earth's climate system. They allow climate scientists to examine how phenomena such as changes in sunlight, greenhouse gases, aerosols, volcanoes, and earth orbital changes impact the earth's climate.

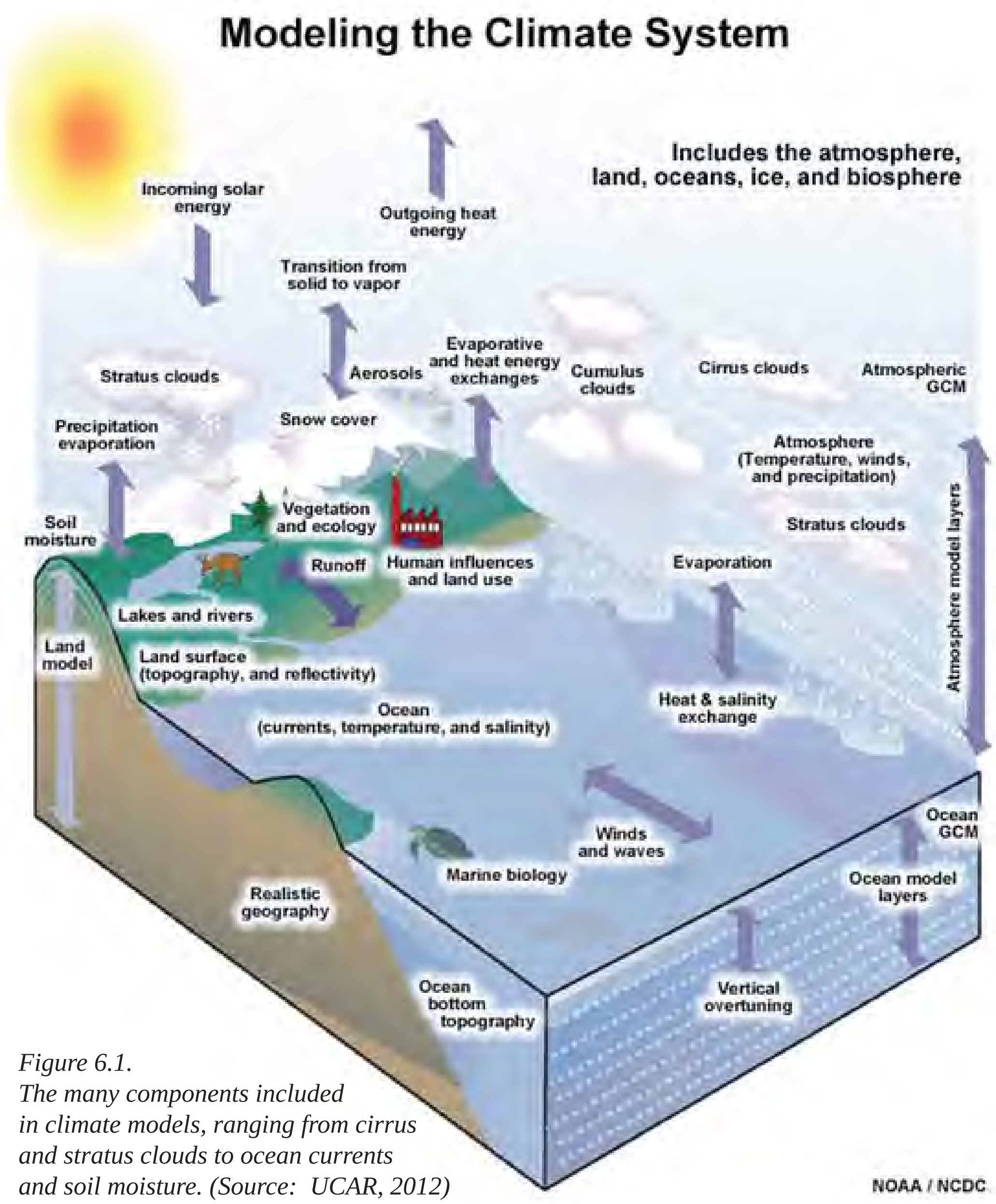


Figure 6.1.
The many components included in climate models, ranging from cirrus and stratus clouds to ocean currents and soil moisture. (Source: UCAR, 2012)

What ARE Climate Models? How Do They Work?

In order to simulate climate properly, we have to calculate the effects of all the key processes operating in the *climate system*. Many of these key processes are represented in Figure 6.1. Our knowledge of these processes can be represented in mathematical terms, but the complexity of the system means that the calculation of their effects can, in practice, only be performed using a computer. The mathematical formulation is therefore implemented in a computer program, which we refer to as a *climate model*. It is important to realize that these climate models are very similar to the models used for weather prediction and forecasting. Current climate models are widely considered to do a credible job at simulating the observed present-day climate, suggesting that we have a high degree of understanding about how the climate system works.

Weather and climate models are the equations of fluid motion, physics, and chemistry, applied to the atmosphere. Essentially, they are the same kind of model—the difference is in how they are used. When the model is used for weather forecasting, an initial state (today's weather) is projected forward in time for one to two weeks. These provide the raw material for the weather forecasts obtained from TV or the Internet. When the model is used for climate projections, many daily weather patterns are simulated, corresponding to imposed boundary conditions or forcings (such as human emissions of greenhouse gases). These daily weather patterns are then processed to obtain model climate statistics, in the same manner by which actual daily weather observations are processed to produce real climate statistics.

Because the atmosphere is highly variable in space and time, these systems of equations must be solved at a great number of points within the atmosphere (both horizontally and vertically) to predict the changing state of the atmosphere through time (i.e., the weather), as shown in Figure 6.2. If these simulations are conducted over an extended time period, the average state and intrinsic variability of the system (i.e., the climate), can be estimated. Therefore, because of the large number of equations that must be solved at a great many points over an extended time, these models must be run on high-performance computers. Even so, the computational requirements and voluminous data output stress even the most advanced computational facilities, and hamper what we are able to accomplish.

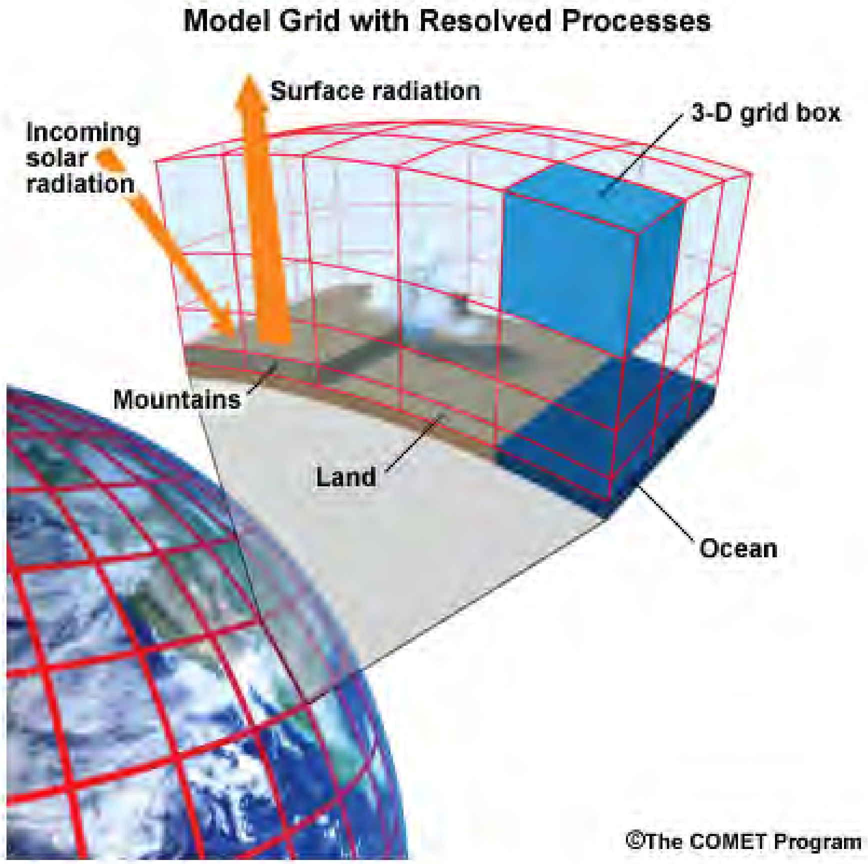


Figure 6.2. Illustration of grid cells (at the surface) and volumes (in the atmosphere) within a numerical climate model. (Source: UCAR, 2012)

In order to simulate future climate change, we must represent possible or expected changes in climate forcing—both natural and anthropogenic (human-induced). Some *natural forcings*—such as changes in solar output—have reasonably well understood physical mechanisms and can be incorporated into projections of the future climate state; other *natural forcings*—such as volcanic injections of gases and particles into the atmosphere—are less predictable. *Human forcings* fall between these extremes—neither highly predictable nor essentially random. These *human forcings*, including emissions of greenhouse gases, have many underlying controls, such as population growth, economic development, and technology. In order to account for these factors, we must develop *scenarios* of how greenhouse gas concentrations will change over time. Once these scenarios are constructed, they may be used as input to climate models to project how the climate system will change in response. The IPCC has developed a number of greenhouse gas emission scenarios, based on different underlying assumptions about economic and technological development over the next century, that were used to project atmospheric greenhouse gas concentrations for use in climate models.

Because we do not have a second earth on which to run climate experiments, nor do we have time to await the results of our current "experiments" on our own earth, climate models, in conjunction with greenhouse gas scenarios, are our best tool for understanding how the earth's climate system will respond to these actual and potential anthropogenic forcings.

Global Climate Models—The General Circulation Model

The General Circulation Model (GCM) is a sophisticated numerical model that attempts to simulate all relevant parts and processes of the climate system. These are sometimes also called "Global Climate Models", though many much simpler climate models could also be referred to as such. The GCM is not actually a true climate model; rather, it is a model that simulates daily weather patterns, which are then statistically aggregated to obtain climatic states, in exactly the same manner by which we use daily weather observations to obtain actual climatic states. In fact, the GCM at its core is very similar to the models used for weather forecasting. There are both atmospheric GCMs (AGCMs) and ocean GCMs (OGCMs). An AGCM and an OGCM can be coupled together to form an atmosphere-ocean (or fully) coupled general circulation model (AOGCM). Because climate change involves interactions between the atmosphere and the ocean, use of the AOGCM has become standard. A recent trend in GCMs is to extend them to become Earth System Models that include such things as submodels for atmospheric chemistry or a carbon cycle model, or interactive (dynamical) vegetation, but these are still very much in a developmental stage.

Regional Climate Models

As it becomes increasingly clear that human-induced climate change is occurring, the Intergovernmental Panel on Climate Change (IPCC) emphasizes that focus is shifting from basic global climate science to understanding and coping with the impacts of climate change. A fundamental aspect of this shift is the need to produce accurate and precise information on climate change at local and regional scales. IPCC and other current projections of climate change rely on global models of climate, which, because of demanding computational resources on even the most powerful supercomputers, must be run at a coarse horizontal resolution (approximately 100 km or 60 miles for many of the models used in IPCC 5th Assessment Report [AR5]). As stressed by IPCC, results at the global scale are useful for indicating the general nature and large-scale patterns of climate change, but not very robust at the local or regional scale (typically 5-15 km or 3-10 miles). This is for two key reasons: 1) global models can only explicitly resolve those physical processes operating over several hundred kilometers or larger; and 2) especially over land, spatial surface heterogeneities can be very large and occur on small spatial scales (for example, regions of complex topography, differing land use patterns, etc.). These spatial heterogeneities can have a profound influence on regional climate, but obviously it can be difficult or even impossible to realistically represent them at the coarse resolution of the global models (Figure 6.2). Yet it is precisely at the smaller 5-15 km scale that most of the impacts from climate change will occur, and need to be understood and dealt with.

Why Climate Models Don't Always Give the Same Results

Climate models are not perfect, and the uncertainty surrounding them is a matter of some controversy and misunderstanding. If we consider the range of uncertainty in the global climate model projections used for the latest IPCC Assessment Report (AR5), the following are important:

1. *The emission scenario considered.* This means the assumed increase in atmospheric greenhouse gases due to human emissions over the remainder of this century. They range from mild increases, which we have probably already exceeded, to the much larger "business as usual" increases. The choice of emission scenarios is the largest single source of uncertainty, and it is crucial to emphasize that which scenario unfolds has *nothing to do with climate models* and *everything to do with human behavior.*

2. *Model physics and handling of feedbacks.* This is the major source of discrepancy between the solutions for the various GCMs *for a given emission scenario*. It is important to note that *all* of the models suggest a strong response, including surface warming, to human-induced increases in greenhouse gases. They differ in the magnitude of that response, and other derivative quantities such as precipitation are therefore more poorly handled. In particular, we know that the water vapor feedback strongly reinforces the basic, or direct, effect of an increase in CO_2 (Box 2.1). While we know that this feedback is real and important, *how* it is handled differs between the models. This is the largest source of *model uncertainty* for a given *emission scenario*.

3. *Horizontal spatial limitations and the need for downscaling*. Another key feature of current global climate mode projections is their relatively coarse horizontal spatial resolution. This is typically on the order of 100 km, which is fine for identifying and simulating important large-scale processes that drive climate at all scales, large and small. This scale is, however, quite coarse when considering crucial climate change impacts at the local scale. This is because the effects of topography and the surface vegetation can strongly influence climate, especially at smaller local scales. In other words, how do changes in the large-scale atmospheric forcing actually translate to changes in the surface climate that really matter to people?

4. *Statistical vs. dynamical downscaling*. Given the need described above in 3), two types of downscaling the output from global climate models to the local scale are typically employed. *Statistical downscaling* uses available station observations to obtain relationships between the large scale (100 km) and the local scale (5 to 10 km). These same relationships are assumed

to hold for future climate change simulations, allowing one to downscale the global results to the local scale. Weaknesses to this method are i) the relationships between the global and local scales may change in the future and ii) many regions do not have an observational dataset robust enough to perform meaningful calculations to establish relationships for the present day.

Dynamical downscaling, on the other hand, employs a high-resolution but limited area regional climate model. This regional model is essentially just a high-resolution (5-10 km) version of its global (100 km) twin. Because climate is global in nature, the regional climate model must be driven at its lateral boundaries by large-scale forcing. Either a global model (GCM) or observations can be used to do so. A major strength is that when observations are used to drive the regional climate model, the output can be compared day to day directly with station observations. This is a level of verification unavailable to global models, for which only the simulated climatology for a region can be evaluated.

Future Model Enhancements

Current climate models are not perfect. They are a reflection of our present understanding of how the climate system operates, and as such are subject to frequent updating and improvement as our knowledge and understanding of key climate processes increases. These improvements fall into two general categories:

1. Better representation of physics. To accomplish this, we require a deeper understanding of some key climatic processes, especially concerning the role of aerosols, as well as clouds and convection (thunderstorms). These are currently active topics of intense research, including by University of Nebraska-Lincoln faculty.

2. Better computational resources and data handling/processing capabilities. Climate models stretch the capabilities of current resources, and have ever since their inception in the 1940s. Indeed, if we could routinely run global models at 5-10 km spatial resolution, then we would not need the downscaling techniques described above.

Although the current models are not perfect, they are nonetheless quite good. They can be used now for climate change impacts assessments. Any future model enhancements will merely allow refinement of these impacts assessments.

Ken Dewey, University of Nebraska–Lincoln

The South Platte River channel near Ogallala, Nebraska, is nearly dry during the severe drought of 2006.

CHAPTER 7

IMPACTS OF CLIMATE CHANGE IN NEBRASKA

Previous chapters of this report have highlighted the observed changes in climate at the global, national, and local (Nebraska) level and projections of future changes during the twenty-first century and beyond. This section of the report is focused on the implications and potential impacts of these changes for Nebraska on several important sectors. Experts with knowledge of and practical experience in these sectors contributed the following commentaries based on information contained in the recently released National Climate Assessment report (NCA, 2014).

Included with the commentaries are Key Messages from the NCA report for some of the specific impact sectors addressed in the report. These messages were identified by more than 300 scientists that participated in the NCA process and represent a consensus of the sector and regional experts.

WATER RESOURCES

Key Messages
NCA report, Chapter 3, 2014

1. **Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.**
2. **Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.**
3. **Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.**
4. **Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.**
5. **Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.**
6. **Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.**
7. **Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.**
8. **Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.**
9. **Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the United States.**
10. **In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.**
11. **Increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts. Many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.**

Commentary: The Potential Impacts of Projected Changes in Climate on Groundwater Resources in Nebraska

Mark E. Burbach, Environmental Scientist
Aaron R. Young, Survey Geologist
Jesse T. Korus, Survey Geologist
Conservation and Survey Division, School of Natural Resources, University of Nebraska–Lincoln

Groundwater is inextricably linked to the Nebraska's rich heritage: it maintains its agricultural economy, it is essential to drinking water supplies, and it sustains its diverse ecosystem. More than 80% of Nebraska's public water supply and nearly 100% of its private water supply depend on groundwater. Groundwater irrigation accounts for about 95% of all groundwater withdrawals, and Nebraska leads the nation in irrigated acres, the vast majority of which is sourced from groundwater. Nebraska is among the top four states for groundwater usage. The availability of groundwater varies naturally across the state; some areas have a great deal of groundwater available for consumption while other areas have less. Also, precipitation increases dramatically from west to east across the state; a consequence is that it requires more irrigation water to grow a crop in the west than it does to grow the same crop in the east. Thus, while the groundwater resources that lie beneath Nebraska may indeed be vast, they are also vulnerable: even small changes in groundwater levels can have profound impacts.

Groundwater levels in Nebraska are closely related to climate variability, predominately because of the changing demand for irrigation. The 2012 drought, for example, resulted in the driest growing season on record, with a corresponding record one-year decline in groundwater levels the following spring. Projected changes in climate, even considering the more optimistic projections, portend serious challenges to groundwater resources in Nebraska. The net effect of projected impacts will be increased stress on groundwater resources. Decreasing soil moisture and reduced recharge during the growing season will be particularly challenging. These conditions will be compounded by hotter and drier conditions with an accompanying increase in evapotranspiration during the growing season. Such changes will stress crops and increase demand for groundwater in areas currently needing supplemental irrigation and expand those areas needing supplemental irrigation. Moreover, other groundwater users will be pressed to increase consumption. Thus, pumping stresses will be superimposed on aquifers experiencing decreasing recharge. Groundwater declines in areas of Nebraska with historically significant declines (for example, the southwest portion of the state and areas of the Panhandle) may be exacerbated and other areas not currently experiencing declines may emerge. Furthermore, decreased groundwater levels will impact stream flows, with detrimental effects on Nebraska's fragile ecosystems. Across the state, there will be constraints to development with increasing competition for water among communities, agriculture, energy producers, and ecological needs.

The projected changes in climate will necessitate an evaluation of current water use needs and policies. Changes to current agricultural and landscape practices will require more efficient irrigation practices, drought-tolerant crops, and increased efficiencies in urban water use, among other measures, in order to sustain groundwater resources. Proactive, collaborative management involving all stakeholders is imperative. Efforts to adapt to future climate conditions will require integrating regulation with planning and management approaches at regional, watershed, and ecosystem scales. These efforts will require additional scientific and economic data on groundwater resources. Pursuing sustainable groundwater management may require assessing how current institutional approaches support adaptation in light of the anticipated impacts of climate change.

Jim Swinehart, University of Nebraska–Lincoln

Drilling in the Sand Hills south of Cody, Nebraska in July 2002.

Commentary:
Nebraska's Water Resources in a Changing Climate

Francisco Munoz-Arriola, Assistant Professor
Derrel Martin, Professor
Dean Eisenhauer, Professor
Department of Biological Systems Engineering, University of Nebraska–Lincoln

Water is a key element of the weather and climate system, regulating human activities and ecosystem services from local to global scales. Changes in water availability reflect changes in the intensity of the water cycle, globally showing its interdependence with climate, and locally highlighting climate- and land use-related impacts. In the Northern Great Plains (NGP), an intensification of the regional water cycle has been observed and projected through increases in the frequency and severity of heavy rainfall events. For example, in Nebraska, a northwest-southeast gradient of observed annual precipitation (15-36 in./year) and projected changes in heavy precipitation (0.4 -1 in. during the 7 wettest days) illustrate the sensitivity of the western portion of the state to recurrent dry conditions. Since increments in precipitation are expected in the winter and spring, also-expected changes in the number of consecutive dry days (-1 to 2 more consecutive dry days) provide evidence of the sensitivity of the southeastern portion of the state to drier conditions during the summer. Either as a product of flood or drought events, changes in the intensification of the water cycle in the NGP and the state influence other components of the water cycle as follows: (1) runoff generation will increase and its seasonal variability will be altered because of changes in snow accumulation, snowmelt timing, and an increasing rainfall/snowfall rate. In response to the increase in extreme events, more effort will need to be made for capturing and storing floodwaters using surface reservoirs and/or artificial groundwater recharge. (2) Evapotranspiration has experienced a declining trend in previous decades, which is projected to continue because of energy changes in the land surface. This change in the fluxes of energy is attributed to the influence of a decreasing activity in land surface-atmosphere interactions, reflected in an increment in cloudiness and humidity and a reduction in solar energy and soil moisture. (3) Soil moisture decline highlights its regulatory role as a limiting factor for ET and groundwater recharge. In this context, projected increments in temperature and variability of precipitation will lead to an alteration of the physical, biological/biogeochemical, and socioeconomic components of the water system, as well as the associations among them. Food and biofuel production in the NGP will be compromised by recurring hydrometeorological extreme events. On one hand, projected flood events due to an early snowmelt and increasing intensity of winter and spring precipitation events may affect the success of winter crops and jeopardize summer crops. The increased recurrence of drought will necessitate an increase in irrigation to reduce the economic risks of winter and summer dryland crop production by utilizing the increased floodwater storage from the spring and winter water surplus. Areas that are already experiencing groundwater depletion, such as southwest Nebraska, may experience further depletion given projected climate scenarios. These scenarios suggest a reduction in summer rainfall across the southern half of Nebraska and, given projections of increasing temperatures and high temperature stress days, this would mean significant changes in current management practices would be required. At the same time, under current nutrient management strategies, there could be an increase of nutrient loads to streams and aquifers, leading to public and livestock health problems. Conservation practices of integrated water quantity and quality management across scales should be addressed, implemented, and continuously improved. In an economy where two out of three jobs are linked to agriculture, and food, energy, and service activities as well as ecosystems services all are dependent on the availability of water, it is crucial to progress and propose novel forms of integrated water resources management in a changing climate.

Ken Dewey, University of Nebraska–Lincoln

The Republican River bed south of Arapahoe in October 2003, covered with grasses and small shrubs.

Commentary:
Implications of a Changing Climate for Nebraska's Water Resources and Its Management

James C. Schneider, Deputy Director
Nebraska Department of Natural Resources

Climate variability has always been one of the most significant challenges to effective and efficient water resources management. The unprecedented and extreme events of 2011 and 2012 highlighted the need for increased resilience in the areas of water planning and management. Nebraska will need an effective and adaptive planning process in order to address the inherent uncertainty in future climate variables. Fortunately, Nebraska is blessed with a vast underground aquifer and extensive surface water infrastructure. Furthermore, with our unique system of local and state involvement in the water planning process, Nebraska has already made great strides in implementing adaptive strategies that change what were zero sum conditions in the past into non-zero sum outcomes for the future. This has been possible through the development and utilization of sound science, matching of state and local funding sources, and building strong partnerships between state agencies, local agencies, and the individual citizens of Nebraska. Although the exact nature of future water supplies and water demands is uncertain, one thing is clear: the challenges for water managers in Nebraska will be significant. In spite of this, the opportunities will continue to outweigh the challenges that come along, and the only potential threat to Nebraska's water future will be ineffective and/or inefficient water management and planning. Nebraska is fortunate to have a proven system of adaptive and integrated water planning, which, if sustained, will mitigate and address any and all water management challenges that arise.

Jim Swinehart, University of Nebraska–Lincoln

Wildflowers bloom around a Sand Hills lake in 2010.

Key Messages
NCA report, Chapter 4, 2014

1. **Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of certain types of extreme weather events are expected to change.**
2. **Higher summer temperatures will increase electricity use, causing higher summer peak loads, while warmer winters will decrease energy demands for heating. Net electricity use is projected to increase.**
3. **Changes in water availability, both episodic and long-lasting, will constrain different forms of energy production.**
4. **In the longer term, sea level rise, extreme storm surge events, and high tides will affect coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.**
5. **As new investments in energy technologies occur, future energy systems will differ from today's in uncertain ways. Depending on the character of changes in the energy mix, climate change will introduce new risks as well as opportunities.**

Commentary: *Potential Impacts of Global Warming on Nebraska's Energy Sector*

Lilyan E. Fulginiti, Professor
Department of Agricultural Economics, University of Nebraska–Lincoln

At least three major climate trends are relevant to the energy sector in Nebraska: increasing air and water temperatures; decreasing water availability; and increasing intensity and frequency of storm events, drought, and flooding. These trends have the potential to affect the ability of Nebraska to produce and transmit electricity from fossil, nuclear, and existing and emerging renewable energy sources. These changes are also projected to affect Nebraska's demand for energy and its ability to access, produce, and distribute bioenergy and biofuels as well as to access and distribute oil and natural gas.

The following circumstances might affect the supply of energy in Nebraska negatively. A decrease in water availability and an increase in air and water temperatures will affect thermoelectric power generation (coal, natural gas, nuclear, geothermal, and concentrated solar power) by reducing the efficiency of cooling, increasing the likelihood of exceeding water thermal intake or the production of effluents that affect local ecology and increase the risk of shutdowns of facilities. An increase in the intensity of storms, droughts, and flooding has the potential of disrupting bioenergy and biofuel production and distribution, oil and gas distribution, and electricity generation and distribution. Decreasing water availability has the potential of affecting production of conventional and unconventional energy, including hydropower; production of bioenergy from crops; hydraulic fracturing; and enhanced oil recovery and refining. Changes in precipitation patterns, increasing temperatures and evaporative losses, and increased frequency and intensity of droughts and floods could affect production of bioenergy, hydropower, and solar power. Higher air temperatures induce less efficient electricity transmission and distribution while more frequent storms increase their risks of physical damage. Frequent droughts and flooding that affect water levels in rivers and ports might interrupt fuel transport by rail and barge. The increased intensity and frequency of flooding increases the risk of physical damage to production facilities and disruption in services.

It is expected that because of climate trends, the demand for energy will increase in Nebraska, barring important increases in efficiency of electricity generation. Global warming is expected to increase cooling degree days (higher than 95°F) more than heating degree days (less *than 10°F) in Nebraska, leading to an increase in the demand for electricity for cooling and a relative decrease in the demand for fuel oil and natural gas for heating. The demand for non-fossil energy sources such as wind power and biomass will increase in the production of electricity and for heating. Peaks of electricity demand might change from summer to winter, with potential cost consequences. Demand of energy for irrigation purposes in agriculture is also expected to increase with expected higher temperatures, more evaporation, less precipitation, more droughts, and decreased snowpack. If biofuels increase as an energy source, this effect is compounded as marginal lands are incorporated to production.*

The energy-water-land nexus is very important in Nebraska, given its role as supplier of renewable energy in the form of wind power and biofuels. Extreme climate events result in cascading effects across energy, water, and land systems. The dependence of Nebraska's energy systems on land and water supplies will influence the development of these systems and the availability of options for reducing greenhouse gas emissions. Increasing population and a growing economy intensify these interactions.

Adam Liska, University of Nebraska–Lincoln

Columbus Powerhouse hydroelectric station.

AGRICULTURE

Key Messages
NCA report, Chapter 6, 2014

1. **Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops and livestock.**
2. **Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.**
3. **Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.**
4. **The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.**
5. **Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.**
6. **Climate change effects on agriculture will have consequences for food security, both in the U.S. and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.**

Commentary:
Climate Change Implications for Nebraska Agriculture

Al Dutcher, State Climatologist
School of Natural Resources, University of Nebraska-Lincoln

Nebraska lies within a region that is commonly referred to as the Great Plains. This region extends from North Dakota southward through Texas and was dominated at the time of settlement by vast grassland ecosystems. It is also an area where normal annual precipitation declines one inch for every 20 to 25 miles as one travels westward. Temperatures across this region can be extreme, with the difference between the all-time maximum and minimum temperature at individual locations ranging from 130°F to 170°F.

Climatic records indicate that the Great Plains have fluctuated between distinct periods of drought conditions and ideal growing conditions. Cool and wet conditions dominated the 1900s-1920s, drought and extreme heat were common during the 1930s and 1950s, and wet and warm conditions with low drought frequency were common during the 1980s and 1990s.

Climate records for Nebraska indicate that an average of 40% of the annual precipitation typically falls during the May-July period, while only 5 to 7% of the annual total normally falls during the December-February period. Annual totals range from 35 inches at Falls City (southeast) to 17 inches at Harrison (northwest). In a typical winter across southeast Nebraska, 20 to 25 inches of snow are common, increasing to 40 to 45 inches across the northwestern corner of the state.

Weather observations from locations with records dating back to the 1890s have shown through regression analysis that there is a persistent warming trend ranging from 0.5 to 1.5°F per century for annual temperatures. However, the vast majority of this warming has occurred during the winter months, with minimum temperatures rising 2.0°F to 4.0°F per century and maximum temperature increases of 1.0°F to 2.5°F per century. Summer minimum temperatures have shown a general increase of 0.5°F to 1.0°F per century at most locations, but maximum temperature trends generally range from -0.5°F to +0.5°F.

The most recent National Climate Assessment report (NCA, 2014) indicates that temperatures across the Great Plains will rise by 2°F to 5°F by the year 2100 with a high degree of certainty. Predictive skills for precipitation have less certainty, with half of the models supporting increased precipitation and half indicating a drier annual precipitation trend. This lack of predictive skill makes assessing crop impacts difficult, but not impossible.

A 10% increase in winter precipitation translates to an increase of 0.15 to 0.25 inches of moisture compared to a 0.80 to 1.10 inch increase in summer precipitation when using the current baseline normal period of 1981-2010. The additional moisture received during the winter months will likely be offset by increased surface evaporation from warmer temperatures that reduce the depth and length of the soil freeze period.

If the National Climate Assessment report is correct with regard to an increase in severe storm events, it may significantly impact the ability of producers to plant crops under optimal field conditions. An increase in storm activity and heavy rain events during the months of April and May could result in crops emerging later than normal, increasing their vulnerability to summer heat. Heavy rains after planting could lead to poor stand emergence, erosion, excessive nitrogen loss, higher disease incident, and increased hail damage losses.

Research conducted by the High Plains Regional Climate Center has found that the date when 4-inch soil temperatures under bare soil are occurring is nearly two weeks earlier than in the early 1980s. What little moisture might be gained during the winter months in a warming environment would be lost to increased evapotranspiration from vegetation that breaks dormancy earlier in the year.

By the year 2100, the National Climate Assessment report indicates that the frost-free season will increase by 30 to 40 days for Nebraska. A shift to earlier planting dates will only be effective if the spread of the distribution curve remains consistent. Vulnerability to freeze damage would increase if the mean freeze date shifts earlier into the year, but the distribution does not shift by an equal proportion. This is a critical issue for producers, as the 2012, 2013, and 2014 growing seasons produced hard freeze conditions during the first half of May, even as favorable soil temperatures are occurring two weeks earlier when compared to the early 1980s.
If precipitation amounts remain steady or decrease by the year 2100, evapotranspiration demand will result

in less moisture available to growing crops during their critical reproductive periods that occur in May (wheat), July (corn), and August (sorghum, soybean). During 2012, native vegetation broke dormancy a month earlier than normal and soil moisture reserves were depleted across most of the U.S. Corn Belt well before the critical pollination period was reached.

There is a general thought that as the climate warms, crop planting dates can be shifted earlier in the year, thus decreasing the likelihood that plants will come into reproduction during the statistical peak of the summer heat. The drought of 2012 proved this theory invalid when precipitation was insufficient to keep plants out of perpetual water stress conditions.

The drought of 2012 exposed limitations of water supplies and the impacts that continuous irrigation had on rural water supplies and energy distribution. Irrigators were forced to apply water on a continuous basis for more than two months, resulting in rolling blackouts due to insufficient infrastructure to meet power demands. Nearly 200 communities were impacted as localized aquifer levels decreased to the levels where community wells were drawing air.

If temperatures do increase during the growing season and precipitation decreases as indicated by the National Climate Assessment report, rural water supplies will be more vulnerable to shortages because of competition from irrigation. Irrigators may face allocation restrictions that set limits on the amount of water that can be applied on an annual basis, and these restrictions may force producers to seek alternative crops to grow under a water-limiting environment.

Commentary: Climate Change Effects on Domestic Livestock

Dr. Terry L. Mader, Professor Emeritus
Department of Animal Science, University of Nebraska–Lincoln

Animal productivity is optimized within narrow environmental conditions. When conditions are outside thermal boundaries for ideal animal comfort and productivity, efficiency is compromised because of alterations in feed intake and maintenance requirements. Shifts in environmental conditions, brought about through climate change, could affect animal agriculture in four primary ways: (1) feed-grain production, availability, and price; (2) pastures and forage crop production and quality; (3) animal health, growth, and reproduction; and (4) disease and pest distributions (Rötter and Van de Geijn, 1999). Productions systems that already utilize enclosed structures (i.e., barns) and heat abatement strategies to modify environmental conditions (i.e., swine and poultry sectors) are probably more likely to tolerate and adapt to future climate change. Nevertheless, despite modern heat-abatement strategies, summer-induced poor performance still costs the American swine industry more than $300 million annually (St. Pierre et al., 2003). Thus, the impacts of climate change and rising CO_2 *are certain to affect all major food-producing domestic livestock species (Mader et al., 2009). Animals managed in unsheltered and/or less buffered environments, such as goats, sheep, beef cattle, and dairy cattle, are particularly vulnerable. Furthermore, climate change will likely have far-reaching consequences for dairy, meat, and wool production systems that rely on grass and range lands to meet some or most of their nutritional requirements. Of particular concern are changes in vegetation that could cause a reduction in forage yield and nutritive value or a shift to less desirable plant species (Morgan et al., 2008).*

Within limits, animals can adapt to and cope with most gradual thermal challenges. However, the rate at which environmental conditions change, the extent to which animals are exposed to extreme conditions, and the inability of animals to adequately adapt to these environmental changes are always a concern (Mader, 2003). Lack of prior conditioning to rapidly changing or adverse weather events most often results in catastrophic deaths in domestic livestock and losses of productivity in surviving animals. Animal phenotypic and genetic variation, management factors (facilities, stocking rates, and nutrition), physiological status (stage of pregnancy, stage of lactation, growth rate), age and previous exposure to environmental conditions will also alter the impact of adverse environmental conditions (Mader and Gaughan, 2012). The recent climate assessment suggests that by the turn of the century, Nebraska will have more than 30 more frost-free days, annually; however, that will be accompanied by more than 40 additional hot nights. High nighttime temperatures limit the ability of animals to cool down at night, a key component to maintaining productivity under daytime heat stress.

Adapting to climate change is certain to entail costs such as application of environmental modification techniques, use of more suitably adapted animals, or even shifting animal populations. An approach is needed that will allow appropriate changes to occur in a timely manner while avoiding undo disturbance of the socioeconomic structure of the livestock production systems. A greater understanding of the animal and grassland responses to environmental challenges is essential to successful implementation of strategies to ameliorate negative impacts of climate change. Because livestock products are an incredibly important human food, and because animal production makes a significant contribution to the Nebraska economy and American GDP, it is necessary to identify climate change mitigation strategies and solutions.


Galen Erickson, University of Nebraska–Lincoln

Cattle graze at the Agricultural Research and Development Center (ARDC) north of Lincoln, Nebraska. Higher daytime and nighttime temperatures in association with climate change provide added stress to livestock.

Commentary: Adapting Nebraska's Agriculture to a Changing Climate

Charles Francis, Professor
Department of Agronomy and Horticulture, University of Nebraska–Lincoln

The National Climate Assessment report (NCA, 2014) predicts an increase in extreme weather events, marked lengthening of growing seasons, and increased precipitation in Nebraska in the short term. A conventional response will be modifying production practices and seeking longer-season varieties of maize and soybeans. Although useful to adapt current crops to changing conditions, such "monoculture thinking" ignores creative potentials for testing new crops and cropping systems. Especially important are possibilities of introducing more biodiversity in time (rotations) and in space (multiple species in the field), and modifying the structure of agriculture, to provide greater farming systems and community resilience in the face of climate change.

Crop rotations, including more species than maize and soybeans, can provide increased efficiency in nutrient and water use, contribute a diversity of crop residues, and prevent or reduce many pest problems, especially by breaking life cycles of weeds and insects. Rotations of legumes with cereals, winter with summer crops, row crops with drilled crops, and annuals with perennials can be effective because of different crop life cycles, abilities to explore multiple soil strata, and use of nutrients, water, and light at different times of the year.

Researching potentials of new or underutilized crops such as sunflower, millets, grain sorghum, flax, and others well adapted to Nebraska conditions can improve yields and contribute to diverse rotations. Mixtures of cover crops planted together with annual crops can provide year-round soil cover to reduce soil erosion and improve soil fertility and structure.

Spatial diversity can provide greater resilience in cropping system performance by mitigating the impacts of severe weather events. Shelterbelts or windbreaks mitigate the force of high winds and also reduce crop transpiration in a dry Nebraska climate, both contributing to productivity. Innovative systems of strip cropping two or more crops—maize, soybean, winter cereal—provide erosion control, rotation patterns within the field, and windbreak contributions from the taller maize crop. Relay cropping—planting soybean into developing winter wheat in the spring—can provide up to 50% greater total system production if rainfall is adequate or irrigation is available. Most of these systems are impractical with current farm and field size, due to the large equipment currently used, but they represent an ecological intensification that could have potential to increase and stabilize yields under conditions of weather uncertainty.

The NCA report describes landscape fragmentation as a negative aspect of current land use trends, yet spatial diversity is a key characteristic of Great Plains natural ecosystems and perhaps holds clues for future farming more sustainable than current wide-scale monocultures. Different crops can be planted in the best specific niches for available resource use, livestock can be integrated with crops to utilize both improved forages and crop residues, spatial diversity can provide new and resilient production, and perennial polycultures of cereals and legumes are future opportunities.

Ken Dewey, University of Nebraska–Lincoln

Center-pivot irrigation of a corn field in Nebraska. Increasing high temperature stress and more variable rainfall will add to the demand for irrigation in future decades.

FORESTRY

Key Messages
NCA report, Chapter 7, 2014

1. **Climate change is increasing the vulnerability of many forests to ecosystem changes and tree mortality through fire, insect infestations, drought, and disease outbreaks.**

2. **U.S. forests and associated wood products currently absorb and store the equivalent of about 16% of all carbon dioxide (CO_2) emitted by fossil fuel burning in the U.S. each year. Climate change, combined with current societal trends in land use and forest management, is projected to reduce this rate of forest CO_2 uptake.**

3. **Bioenergy could emerge as a new market for wood and could aid in the restoration of forests killed by drought, insects, and fire.**

4. **Forest management responses to climate change will be influenced by the changing nature of private forestland ownership, globalization of forestry markets, emerging markets for bioenergy, and U.S. climate change policy.**

Commentary:
Impacts of Projected Climate Changes on Nebraska's Tree and Forest Resources

Dr. Scott J. Josiah, State Forester and Director
Nebraska Forest Service, University of Nebraska–Lincoln

According to the USDA Forest Service, forests in Nebraska occupy approximately 1.5 million acres, with an additional 1.5 million acres of nonforest land with trees. Nebraska's forests are unique in that they generally exist on the eastern, western, or southern edges of their native ranges, and grow under stressful conditions more conducive to prairie ecosystems than to forests. These tree and forest resources provide critically important economic and ecosystem services.

Changes in Nebraska's climate, projected in the National Climate Assessment report (NCA, 2014), will have, and arguably are having, substantial and negative impacts on the state's tree and forest resources. Increased incidence and severity of drought and severe weather events, and higher day and night temperatures, will seriously affect the health, vitality, and resilience of individual trees and urban and rural forest ecosystems.

More intense droughts compounded by higher temperatures and excessive forest fuel loads have already damaged trees and forests across the state, substantially increased the risk to life and property because of catastrophic wildfires, and reduced sequestration and storage of atmospheric carbon. Large wildfire events have increased in frequency and size over the past 50 years (Figure 7.1). Repeated intense and uncharacteristic wildfires occurring in the Ponderosa pine forests of the Pine Ridge in northwestern Nebraska have reduced forest cover from 250,000 acres to less than 100,000 acres since 1994. These forests burned so intensely that nearly all living trees were eliminated across large landscapes, converting former forests to grassland. Intense wildfires driven by projected increases in temperature and drought will gravely threaten Nebraska's remaining pine forests. Given that these forests represent the easternmost extension of Ponderosa pine in North America, their loss would eliminate unique genetic adaptations to low elevation, hotter conditions.

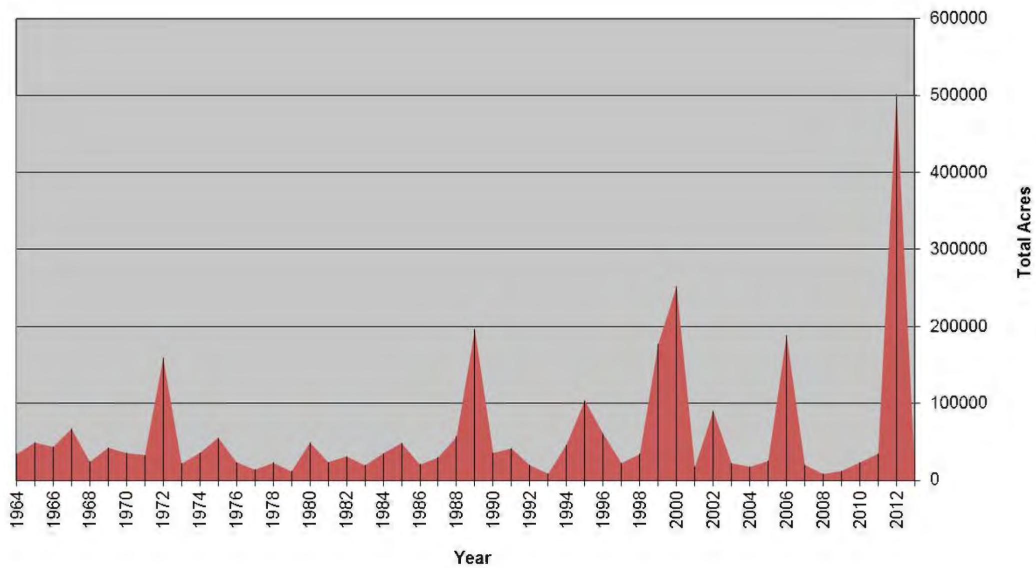


Figure 7.1. Nebraska wildfire acres burned in 50 years of history, 1964-2013.

Higher temperatures, especially those at night, combined with drought reduce carbohydrate reserves essential for vigorous growth and pest resistance, often for several years. The population of pests (such as the Mountain Pine Beetle, Dendroctonus species*) that were limited by very cold temperatures is now achieving much higher overwintering success because of warmer winters. Nebraska's pine forests lost thousands of trees in the 2000s from Mountain Pine Beetle attacks, which were part of a massive outbreak devastating forests across 35 million acres in North America. Engraver beetles (*Ips species*) are currently attacking and killing heat- and drought-stressed pines across the Pine Ridge and Niobrara Valley. Increasing temperatures and drought also negatively affect urban forests, disproportionately killing nonnative tree species (such as white pine and spruce) that are poorly adapted to these changing conditions. Reduced vigor and increased mortality of trees in urban areas will further decrease the capacity of urban forests to mitigate higher urban temperatures, compromising human health.*

Nebraska has historically experienced a wide range of severe weather events. The predicted increased frequency and intensity of such events will clearly and negatively impact trees and forests statewide. The unprecedented flooding of 2011 along the Missouri River inundated 26,000 acres of bottomland forest in Nebraska for nearly the entire growing season. Large-scale mortality occurred, as few native riparian forest species are adapted to such long periods under water. Other severe weather events common to the Plains (tornados, straight line winds, ice and early winter snow storms, early fall and late spring freezes, etc.) already damage Nebraska's trees and forests. An increase in frequency and intensity of these events will likely substantially increase these losses. The loss of windbreaks and forested riparian buffers from more frequent severe weather events will increase soil erosion, impair air and water quality, and decrease crop yields and quality across Nebraska.

Options to address the challenges of climate change for Nebraska's trees and forests are limited. Increasing species and seed source diversity will enhance resilience of urban and conservation plantings. Thinning coniferous forests reduces competition for water, improves tree vigor, protects remaining islands of live forest stands isolated by previous wildfires, and decreases the risk of catastrophic crown fires. Developing new products and markets for wood, especially for bioenergy applications, creates market drivers that support expanded forest thinning operations, and offsets the use of fossil fuels and further releases of ancient CO_2. Large-scale tree planting campaigns will be increasingly needed to replace trees and forests damaged or killed by severe weather events and more stressful climate conditions aggravated by climate change.

Key Messages
NCA report, Chapter 9, 2014

1. **Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, threats to mental health, and illnesses transmitted by food, water, and disease-carriers such as mosquitoes and ticks. Some of these health impacts are already underway in the United States.**

2. **Climate change will, absent other changes, amplify some of the existing health threats the nation now faces. Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color.**

3. **Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited.**

4. **Responding to climate change provides opportunities to improve human health and well-being across many sectors, including energy, agriculture, and transportation. Many of these strategies offer a variety of benefits, protecting people while combating climate change and providing other societal benefits.**

Commentary:
Climate Changes and Human Health: Implications for Nebraska

Andrew Jameton, Professor Emeritus
University of Nebraska Medical Center

The Third National Climate Assessment report (NCA, 2014) identifies many likely health effects of climate change on Americans. Effects shared by Nebraskans include:

Heat waves, marked by a combination of high temperature and humidity, will pose physical and mental health challenges. Outdoor work and recreation will become more difficult, riskier, and less productive.

Dry air, dust, allergens (such as ragweed), and ground-level ozone will increase as the climate changes. Variously and in combination, these factors increase allergies, asthma, bronchitis, and other lung and circulatory problems. Wildfires, high winds, and dust storms will spread toxic chemicals and particulates, both current (as from wildfires) and historical (as from previously employed agricultural chemicals). Existing methods of power production, especially coal plants, are drivers of both climate change and important air pollutants.

Declining water quality will challenge individual hygiene and public sanitation systems. Toxic chemicals, algae, and water-borne diseases (such as salmonella and giardiasis) will likely become more widespread. Intensifying conflict over diminishing water quantity will stress people and their communities. Thousands of private wells will need increased health monitoring. Wells for public water supplies are likely to take in more pollutants.

Most studies indicate that in the multi-decadal perspective, agricultural output is likely to decrease substantially. Cattle in particular suffer from excessive heat. As productivity declines, food prices are likely to increase, reducing the ability of consumers to purchase quality caloric and micronutrient diets. Nebraska-based agricultural drought will not be the only factor in challenges to the nutrition of Nebraskans. Since much of the Nebraskan diet is imported from such states as California and Arizona, drought in exporting regions will likely reduce Nebraskans' access to fruit and vegetables. Food safety is likely also to decrease: heat-stressed corn crops are likely to display increased growth of the carcinogen aflatoxin. Agricultural products will likely be grown in increasingly contaminated water.

It is unclear whether severe wind storms, such as tornadoes and hail storms, are becoming more likely, but the evidence is that the Great Plains can expect *increases in floods, dust storms, downpours, and wildfires. Such extreme weather events cause death and extensive physical and psychological trauma. They spread contaminants and reduce the capacities of emergency response and basic health care facilities. Potential long-term health effects of these extreme events are often overlooked (such as mosquito-borne diseases, indoor dampness and mold, and depression after flooding). Although Nebraska can expect fewer cold-related injuries, there is likely to be an increase in the number of large winter ice storms.*

Global and national climate changes are shifting diseases into Nebraska. Common disease vectors such as mosquitoes, ticks, and rodents are of particular concern since they carry dangerous diseases, such as West Nile and the plague virus (hantavirus). Human-to-human infections (such as HIV and TB) can also be expected to shift with changing patterns of human habitation.

The economy is one of the most significant factors affecting health. Agricultural failures, infrastructure damage, revenue and capital shortages, the costs of health care, poverty, food prices, and so on will have important and unpredictable effects on health. Economic effects on health include anxiety and depression, suicide, poor nutrition and sanitation, reduced access to health care, and conflict.

The NCA report underlines the importance of identifying vulnerable populations at risk, such as the poor, Native Americans, people of color, the elderly, children, and those suffering from chronic and acute illnesses. Nebraska Indian reservations may experience significant drought, and reservation populations cannot easily move away.

Documenting these concerns tends to be a source of worry. However, Nebraskans should not be discouraged from undertaking adaptive and mitigative efforts. Although the NCA report notes that "existing adaptation and planning efforts are inadequate to respond to these projected impacts" (Key Message 5, Chapter 19), the authors may not have been aware of extensive Nebraska-based planning efforts already in place with regard to drought and its consequences.

Moreover, as the report also concludes (in Key Message 3, Chapter 9), early and committed preparedness and prevention can do much to reduce health problems and provide important health benefits. Suggested projects with such co-benefits include improved early warning systems and shelters for extreme weather events, strengthening the resilience of sewage systems, increased exercise programs, and improvements in diet.

Ken Dewey, University of Nebraska–Lincoln

A summer thunderstorm develops in the Sand Hills of Nebraska. The increased intensity of rainfall is one of the trends associated with climate change in the Great Plains and other parts of the country. This trend is expected to continue.

Key Messages
NCA report, Chapter 8, 2014

1. **Climate change impacts on ecosystems reduce their ability to improve water quality and regulate water flows.**

2. **Climate change, combined with other stressors, is overwhelming the capacity of ecosystems to buffer the impacts from extreme events like fires, floods, and storms.**

3. **Landscapes and seascapes are changing rapidly, and species, including many iconic species, may disappear from regions where they have been prevalent or become extinct, altering some regions so much that their mix of plant and animal life will become almost unrecognizable.**

4. **Timing of critical biological events, such as spring bud burst, emergence from overwintering, and the start of migrations, has shifted, leading to important impacts on species and habitats.**

5. **Whole system management is often more effective than focusing on one species at a time, and can help reduce the harm to wildlife, natural assets, and human well-being that climate disruption might cause.**

Commentary:
Climate Change Effects on Biodiversity and Ecosystems

Rick Schneider, Coordinator, Nebraska Natural Heritage Program
Nebraska Game and Parks Commission

Climate change is having significant impacts on species and ecosystems, and these are likely to increase in the future (Lovejoy and Hannah, 2005; Parmesan, 2006; National Research Council, 2008; Staudt et al., 2013; Groffman et al., 2014). These impacts include changes in species distributions, alteration in the timing of annual life-cycle events, and disruption of ecological relationships. Climate change is also altering ecological processes such as fire and hydrologic regimes, which will affect species as well as ecosystem structure and function. In addition, climate change will exacerbate the effects of nonclimate stressors such as habitat loss and fragmentation, pollution, and the spread of invasive species, pests, and pathogens.

Climate is one of the primary factors determining the distribution of wild plants and animals. There is good evidence from the past of how species respond when the climate changes. As the world warmed following the last ice age, species moved to higher latitudes, or upslope in mountainous areas, following a climate to which they were adapted. We are seeing the same pattern under the current climate change. Hundreds of studies have documented species shifting their geographic ranges to higher latitudes, or upslope, in recent decades. As our climate continues to change, Nebraska will lose species whose southern limit of their range is here, while we will gain species from states to the south of us. Some of these new arrivals will no doubt be invasive species, pests, and pathogens.

Although some species will be able to respond to climate change by shifting their distribution, many will not. The current rate of change is many times faster than what occurred following the ice age. Species with limited ability to move, such as many plants and invertebrates, will simply not be able to keep up as the climate to which they are adapted moves on. In addition, the natural landscape, particularly here in Nebraska, is now highly fragmented by human development such as cropland, highways, dams, and cities. This development forms a barrier to the movement of many species and will inhibit their ability to respond to climate change. Those species that cannot move to more suitable locations or otherwise adapt to changing conditions will likely face local extinction. Both range shifts and local extirpations will lead to changes in the species composition of natural communities, resulting in new communities that may bear little resemblance to those of today.

The changing climate is also affecting the timing of annual events in the life cycle of species. Numerous studies have documented recent shifts in the timing of events such as migration, insect emergence, flowering, and leaf out—all driven by the earlier arrival of spring. Species are not expected to respond uniformly to climate change. Thus, there are likely to be disruptions of ecological relationships among species as they respond to climate change in different ways and at different rates. For example, the timing of emergence of an insect pollinator may shift and become out of sync with the flowering time of its host plant. Disruption of species relationships may lead to local extinction and have significant impacts on ecosystem structure and function.

While all ecosystems in Nebraska will be affected by climate change, aquatic ecosystems (wetlands, lakes, streams, and rivers) may be the most highly impacted. Climate changes will alter both water quality and quantity. Increases in the frequency and intensity of high precipitation events, particularly in a landscape dominated by agriculture, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies. Increased frequency of drought and heat waves, combined with increased human demand for water, will result in lower stream flows and an increase in the frequency of stream segments being de-watered and wetlands drying up. Finally, increases in air temperature will result in increases in water temperature, causing a reduction in suitable habitat for cold-water dependent species such as trout. In an analysis by the Nebraska Game and Parks Commission, mollusks, amphibians, and small stream fishes were found to be the most vulnerable to climate change of all groups of plants and animals considered.

The conservation community, including staff at state and federal natural resource agencies, nonprofit conservation organizations, and universities, has been working to develop and implement strategies to help wildlife adapt to climate change. These strategies include restoring and maintaining connectivity between habitats to allow species to shift their range, reducing the impacts of nonclimate stresses, and restoring and maintaining key ecological processes. The National Fish, Wildlife and Plants Climate Adaptation Strategy (National Fish, Wildlife and Plants Climate Adaptation Partnership, 2012) provides an excellent summary of climate change impacts on biodiversity and strategies to address those impacts.

Commentary: As Our Climate Changes. What Can We Do for Ecosystem Health?

Mace A. Hack, State Director in Nebraska
The Nature Conservancy

The Third National Climate Assessment (NCA) (2014) updates the growing body of evidence for significant climate changes occurring now in the Great Plains. With each added year of data collection and analysis, speculation on how these changes will affect our lives in Nebraska is giving way to discernible patterns and greater certainty that human-driven climate change is here to stay. For sure, there is much we do not yet know and we must continue our research, but we ignore the emerging patterns at our own peril. Healthy, functioning ecosystems underpin our economy and our well-being in Nebraska through their provision of clean water, clean air, and abundant forage for ranching, and other vital services. We need to reduce our greenhouse gas emissions to forestall even more extreme climate changes over the next decades and also develop adaptation strategies to maintain the character and functioning of our most important ecosystems.

Anyone who's lived a full year in Nebraska can appreciate how extreme our weather in the Great Plains can be, varying dramatically across days and seasons. Our major ecosystems in Nebraska—primarily grasslands, wetlands, and rivers—have evolved under the selective pressures of high climate variability. Drought and flood years seem more the norm than years of "average" precipitation. Whether this evolutionary history provides greater built-in resilience to the climate changes we anticipate over the next decades remains an open question. It is clear, however, that our natural ecosystems in Nebraska have resilience-providing features that managers can draw on in developing adaptation strategies.

Floodplains are natural features of our major river systems that we should utilize more effectively to buffer expected climate changes, principally increased flood risk from more intense precipitation events. The broad floodplain of the Missouri River, for example, would naturally absorb floodwaters and release them slowly back into the main channel, reducing flood heights, if they weren't almost entirely walled off from the main channel by levees. Strategic reconnection of the river to its floodplain in places where it is not developed would reduce flood risks in developed reaches of the river where *flood damage would be greatest. The alternative is to continue building higher and stronger levees all along the river, a very expensive option that history suggests may not provide the long-term protection we need. Floodplain reconnection has the added benefits of restoring natural habitats, providing outdoor recreation, and utilizing the natural water-cleansing properties of wetlands to improve water quality.*

The high diversity of plant species that characterizes our native grassland ecosystems may present another example of naturally evolved resilience to climate variability. Because each plant species thrives under slightly different climatic conditions, a grassland with 150 species of plants will be more likely to have some species in a given year that do well, maintaining the grassland's character and productivity, versus a grassland with only 15 species where none may thrive under that year's climatic conditions. This argues for an adaptation strategy that maximizes the naturally occurring plant diversity in our grasslands. Long-term, we might expect these systems to see a change in species composition but still remain as well-functioning grasslands.

More than anything, the implications of climate change for Nebraska's ecosystems should shake us from the complacency that our small network of public and private lands managed for the conservation of natural communities and wildlife will be sufficient to preserve these resources in the decades ahead. We must expand our scope to develop conservation strategies at the scale of whole ecosystems, forge new public-private partnerships to implement them, and increase our monitoring of long-term changes in natural communities to adapt our efforts over time.

Commentary: Climate Change and Invasive Species

Tala Awada, Professor
School of Natural Resources, University of Nebraska–Lincoln

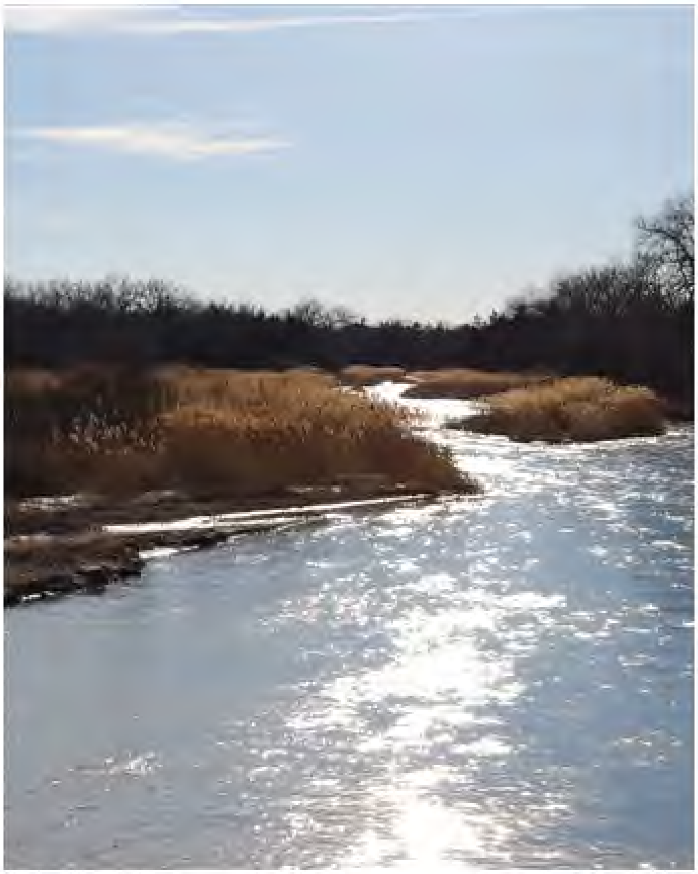
Plant species composition and distribution in native and managed ecosystems are undergoing constant and unprecedented change, which has been attributed to climate change, disturbances, and anthropogenic management (Eggemeyer et al., 2009; Wilcox, 2010; Pintó-Marijuan and Munné-Bosh, 2013). Climate affects fundamental biological and physiological processes in plants and interacts with existing environmental stressors and disturbances, causing a change in plant biodiversity, phenology, and distribution and affecting the spread, abundance, and impacts of invasive species, which leads to ecological, biogeochemical, ecohydrological, and economic consequences and potential negative impacts on human health (Hellmann et al., 2008; Awada et al., 2013).

*Invasive plant species are defined as species whose populations are able to thrive, reproduce, and spread aggressively beyond the location of introduction. Numerous well-known nonnative species that were introduced to the United States for purposes like horticulture, agriculture, habitat for wildlife, and windbreak and/or soil stabilization have become invasive. In Nebraska, examples include purple loosestrife (*Lythrum salicaria*), musk thistle (*Carduus nutans*), common reed (*Phragmites australis*), leafy spurge (*Euphorbia esula*), Russian olive (*Elaeagnus angustifolia*), and salt cedar (*Tamarix spp.*). Under climate change, plant taxa will shift their geographic distribution, and species previously considered invasive may become noninvasive, or vice versa (Hellmann et al., 2008). Many studies, however, suggest that climate change will, on average, favor the expansion of invasive species and aggressive native encroachers, rather than limit or reduce their spread, because of their broad range of genetic tolerance, phenotypic plasticity, and traits associated with resource acquisition and growth (Pyŝek and Richardson, 2007; Bradley, 2014), which enable them to survive and expand across a wide range of environmental conditions (Pintó-Marijuan and Munné-Bosh, 2013). For instance, in Nebraska and other regions of the Great Plains, factors like climate change, shift in disturbance regime (for example, fire suppression and flood control), and management practices have led to the aggressive encroachment of native woody eastern red cedar (*Juniperus virginiana*) into warm-season semiarid grasslands, and the spread of introduced Russian olive into the native eastern cottonwood (*Populus deltoides*) riparian forests (Huddle et al., 2011; Awada et al., 2013).*

Extreme weather and climate events (for example, severe heat waves and droughts, hurricanes, and floods) associated with climate change may further decrease ecological resistance in native communities and promote invasive species spread through native species mortality and increased resource availability after disturbances

(Diez et al., 2012). In some rare cases, extreme events can restore native communities. For example, flooding in riparian zones can negatively impact woody invaders like eastern red cedar and favor native woody species regeneration (Huddle et al., 2011). Invasive species have also been found to interact positively among each other (invader to invader), facilitating the entry and spread of other invasive species and leading to what has been termed an invasional meltdown *(Green et al., 2011). Eventually, successful invasion into a community depends on the genetic characteristics, phenotype, and plasticity of the invader, the disturbance regime or extreme events, and the resilience of the native community.*

Invasive plant species have found a recipe for success by combining reproductive success with stress resistance (for example, to drought and salt) within the frame of climate change (Pintó-Marijuan and Munné-Bosh, 2013). As the need for landscape plants adapted to heat and drought increases because of water restrictions and climate change (Bradley et al., 2012), global trade with new partner countries and regions in the horticulture industry is emerging. This places us at risk of a whole new generation of potential invaders. Therefore, active management approaches are imperative to reduce risks from new species. This can be accomplished by preemptive screening for "invasion potential" of plants prior to import (Bradley et al., 2012). Predictors for species risk evaluation, such as history of invasion, range of climatic distribution, and dispersal and reproduction strategies, are recommended.



Brian Crabtree, Nebraska Weed Control Association

Dense stands of invasive phragmites on the Missouri River. It forms dense stands over very large areas, restricting water movement.

URBAN SYSTEMS, INFRASTRUCTURE AND VULNERABILITY

Key Messages
NCA report, Chapter 11, 2014

1. **Climate change and its impacts threaten the well-being of urban residents in all U.S. regions. Essential infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts. The nation's economy, security, and culture all depend on the resilience of urban infrastructure systems.**

2. **In urban settings, climate-related disruptions of services in one infrastructure system will almost always result in disruptions in one or more other infrastructure systems.**

3. **Climate vulnerability and adaptive capacity of urban residents and communities are influenced by pronounced social inequalities that reflect age, ethnicity, gender, income, health, and (dis)ability differences.**

4. **City government agencies and organizations have started adaptation plans that focus on infrastructure systems and public health. To be successful, these adaptation efforts require cooperative private sector and governmental activities, but institutions face many barriers to implementing coordinated efforts.**

Commentary:
An Urban Perspective on the Impacts of Climate Change: The City of Lincoln Takes Action

Milo Mumgaard, JD, Senior Policy Aide for Sustainability
Amanda Johnson, BA, Senior Policy Intern
Office of Mayor Chris Beutler

The modern city is a place with a remarkable diversity of people, culture, and entrepreneurial spirit. This describes Lincoln, Nebraska, which added more than 30,000 people in the last seven years alone—the size of most mid-size Nebraska cities—and is set to be home to nearly 400,000 residents by 2040.

Naturally, this dynamic growth is causing increased stress on Lincoln's existing infrastructure, including for water, energy, transportation, and stormwater control. At the same time, Lincoln's leaders recognize that climate change is also causing new and expanding stresses on the city's infrastructure. The National Climate Assessment report (NCA, 2014) and other climate assessments tell us that we should expect many more sizzling triple-digit days, more severe storms, and extended droughts. These impacts will result in our infrastructure becoming more frequently overloaded, or at times partially or wholly unavailable, unless adaptation measures are strategically implemented now and in the future.

Lincoln Journal Star

Aerial view of Lincoln, Nebraska including Memorial Stadium (left) and the Pinnacle Bank Arena (right). Increasing temperatures and more frequent droughts will have increasing impacts on the urban infrastructure.

It is no longer reasonable for the City of Lincoln to plan based upon historical weather patterns; instead, as we grow we must plan for and adapt to the impacts of climate change. Residents of our growing city expect its leaders to respond to these challenges—after all, these involve the basic expectations of local government.

These impacts are already being felt. The summer of 2012, the warmest and driest on record for Nebraska, was particularly hard on Lincoln since we receive all our drinking water from wells located near Ashland on the Platte River. As this river system goes, reliant as it is on Rocky Mountain snowpack and timely rains, so goes Lincoln's ability to meet its demand for life-giving water.

But these impacts are also being seen in other areas of local responsibility. More frequent high temperature extremes will mean higher peak energy demands, potential reliability risks, and stresses on low-income and elderly populations. Fewer and far more intense rain and snow events can increase local flooding. Digging out from major snowstorms will take longer and be more costly. Fewer hard frosts and longer growing seasons mean more insects and disease. Think of the emerald ash tree borer, poised to eliminate thousands of trees in Lincoln's urban forest, as a harbinger of things to come.

Mayor Chris Beutler's administration is taking action. It is a priority for the city to reduce climate-related vulnerabilities for residents and businesses, and to better respond when impacts occur. Fostering more water conservation and identifying new reliable water sources is happening now, not tomorrow. Helping residents, especially the low-income and elderly, to live in more efficient homes that can withstand hotter summers and lower their health risks is now as important to energy planning as tapping into new renewable sources. Energy building codes are being upgraded to assure high-performing, energy-saving homes and workplaces. More compact urban growth is the goal. New stormwater "best management practices" are now in place, using "green infrastructure" to lessen our floods, better store raging stormwater, and lower urban heat. Examples also abound of actions being taken now by the City of Lincoln to lower its carbon emissions and to help mitigate the impacts of climatic changes we know are affecting us today. The city knows it must continue to incorporate even more climate change resilience and adaptation measures into its daily operations. This is the challenge of the modern city, and it is one Lincoln is already responding to.

Key Messages
NCA report, Chapter 14, 2014

1. **Rural communities are highly dependent upon natural resources for their livelihoods and social structures. Climate change related impacts are currently affecting rural communities. These impacts will progressively increase over this century and will shift the locations where rural economic activities (like agriculture, forestry, and recreation) can thrive.**
2. **Rural communities face particular geographic and demographic obstacles in responding to and preparing for climate change risks. In particular, physical isolation, limited economic diversity, and higher poverty rates, combined with an aging population, increase the vulnerability of rural communities. Systems of fundamental importance to rural populations are already stressed by remoteness and limited access.**
3. **Responding to additional challenges from climate change impacts will require significant adaptation within rural transportation and infrastructure systems, as well as health and emergency response systems. Governments in rural communities have limited institutional capacity to respond to, plan for, and anticipate climate change impacts.**

Commentary:
How Projected Climate Change Would Affect or Further Stress the Viability of Nebraska's Rural Communities

Charles P. Schroeder, Founding Director, Rural Futures Institute
University of Nebraska–Lincoln

Rural Nebraskans have a long history of adapting to their environment, including its changes, challenges, and opportunities involving climate, markets, technologies, and other influences emanating from within and without. However, as we consider projected climate change and its effect on rural Nebraska communities, the words of British innovation strategist Max McKeown should be our guide: "Change is inevitable; progress is not."

The projections for climate changes in the Great Plains indeed contain challenges for Nebraska communities that will require thoughtful planning, preparation, innovation, and purposeful action if Nebraska's legendary resiliency is to dominate those challenges. This will demand strong leadership across many sectors, working collaboratively to solve problems and capture opportunities arising from a changing environment.

Nebraska's rural communities function in a natural resource environment dominating the state's landscape. These natural systems are, of course, vulnerable to climate changes that can challenge the vitality of rural communities. Economic factors for resource-based industries, population movements, demographics within the population, cultural practices, energy demands, and water requirements may all be altered.

Although only 37% of the state's residents live in rural areas, the importance of viable rural communities to the state's economic and social well-being is profound. The intertwining socioeconomic interests of rural and urban communities will be highlighted as climate change affects natural resource systems.

Rural Nebraskans are knowledgeable about and sensitive to climate issues. The Nebraska Rural Poll (2013) tells us:

- *At least two-thirds of rural Nebraskans have experienced: loss of wildlife and wildlife habitat (75%), voluntary decrease in water usage (73%), decreased farm production (69%), and wildfires (69%).*
- *Most rural Nebraskans think climate change is happening, and 69% feel they understand global climate change issues.*

- *Most rural Nebraskans (60%) think change is required to solve global climate change.*

As changes in climate are projected to influence the nature, quality, and abundance of natural resources forming the foundation of Nebraska rural communities, it is a call for proactive response. Improved preparation and coordinated actions involving homeowners, businesses, community institutions, regional organizations, and government agencies at all levels will be required. Rural Nebraska will be challenged by climate changes, but need not be devastated by them. Nebraskans understand natural resources and a natural environment. They are thus uniquely suited to demonstrate collaboration across sectors (government, community, business, education, healthcare, faith organizations, etc.) in both mitigating the factors driving climate change and responding proactively to changes that are inevitable.

Will urban life, particularly on the coasts, become less secure in the wake of climate change? Will rural communities in the Great Plains that have developed strong collaborative models for preparedness and community problem solving related to water, food, and energy become especially attractive?

We know there is a growing trend among young professional families to seek vibrant rural communities where they can build their careers, raise their children, and become engaged civically in a place where they can make a difference. The challenges associated with climate change may also be a platform for engagement of talent flowing to Nebraska rural communities in the future.

Bob Oglesby, University of Nebraska–Lincoln

Driving Highway 2 along the western edge of the Sand Hills near Alliance, Nebraska.

Authors' note: The insurance sector was not one of the sectors included in the National Climate Assessment report. However, it is one of the largest sectors globally and also one of primary importance in Nebraska. The commentary below is provided to raise awareness of the concerns of this sector with regard to climate change and, specifically, the increasing frequency of extreme climatic events.

Commentary: Climate Change and Its Implications for the Insurance Industry

Adam Liska, Assistant Professor
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Eric Holley, Graduate Student
School of Natural Resources, University of Nebraska–Lincoln

As noted previously, climate change will lead to a probable increase in the occurrence of weather-related disaster events. These events could lead to declining revenue in the insurance industry, the world's largest economic sector, with revenue of $4.6 trillion per year, or 7% of the global economy (Mills, 2012). Climatic events have accounted for 72% of global insurance claims and insured losses from 1980 to 2012, totaling $0.97 trillion (Munich Re, 2013). Estimated losses are ~0.5% of global Gross Domestic Product (GDP) and losses are increasing at ~6% a year in real terms (Lomborg, 2010). The United Nations Framework Convention on Climate Change estimated total costs could be 1-1.5% of world GDP in 2030, or $0.85-1.35 trillion per year in 1990 dollars (Lomborg, 2010). It was also recently estimated that $0.24-0.51 trillion worth of U.S. property will likely be below sea level by 2100 (Bloomberg et al., 2014).

In 2013, the World Economic Forum ranked increasing greenhouse gas emissions as the third highest risk by probability for the global economy and failure of climate-change adaptation as fifth in terms of having the most negative impact for the global economy (WEF, 2013). Expert statistical assessment of risks is often inconsistent with the perception of risk by lay persons and professionals in decision making, as reports suggest (Kahneman, 2011; Kunreuther et al., 2001). People who have recently experienced a catastrophe may find it easier to imagine the catastrophe occurring again and feel a higher perceived risk than people who have not experienced the catastrophe (Kahneman, 2011; Botzen, 2013).

The National Catastrophe Service (NatCatService) provided by Munich RE, the world's largest reinsurance company, has extensive data on climatic events and natural catastrophes. The increasing occurrence of natural catastrophes in the United States and globally is of great interest to the insurance industry. North America, Central America, and the Caribbean account for the majority of global insured and overall losses. The NatCatService database underestimates damages from climatic events because only large events are included; although many people see the threat of climate change in the form of major natural disasters, 60% of total insured losses come from smaller events (Vellinga et al., 2001).

Insurance claims in the future may increase considerably if climate change projections and socioeconomic developments result in an increased frequency and magnitude of natural catastrophe damage, as reports suggest (Dlugolecki, 2000, 2008; Mills, 2005; Vellinga et al., 2001). Botzen (2013) argues that socioeconomic developments have been the main reason for the rapid increase of the total amount of damage that has been observed in recent years across the globe. The costs of climate change are also more likely to markedly increase if climate change is abrupt instead of gradual (Botzen, 2013; National Academy of Sciences, 2002). Because of the nonlinear changes associated with a changing climate (for example, projected sea-level rise), experience over the last 50-100 years has been identified as an ineffective predictor of future insurance losses (Mills, 2012).

In 2008, the National Association of Insurance Commissioners (NAIC) noted that "global warming and the associated climate change represent a significant challenge for Americans. As regulators of one of the largest American industries, the insurance industry, it is essential that we assess and, to the extent possible, mitigate the impact global warming will have on insurance" (NAIC, 2008).

In 2010, Nebraska insurance agencies added around $10.3 billion to the state economy and accounted for 5% of total Nebraska payrolls (Thompson and Goss, 2010). It is also estimated that the insurance industry will add ~67,000 jobs, approximately a 3% gain, between 2008 and 2018 (Thompson and Goss, 2010). Nebraska is one of four states (Connecticut, Iowa, and Wisconsin are the others) with a significantly high proportion of outreach from state insurance agencies, meaning these states are exposed to risks from elsewhere (Thompson and Goss, 2010). Roughly $4 billion was reported in premiums by property insurance businesses of Nebraska, with $1.5 billion directly related to weather. Another major source of income for Nebraska insurance is crop insurance. In 2012, Nebraska insurance companies garnered $850 million in premiums based on farm insurance strictly in Nebraska; this is compared to the $14.6 billion in farm premiums in the United States as a whole (NAIC, 2013). The state's wealth and tax revenue is also at risk, with 10% of total GDP coming from insurance and finance alone (NEDED, 2013).

The insurance sector is a potential driver of adaptation to climate change. Mills (2012) notes "the insurance sector is a global clearing-house for climate risks that affect every under-writing area and investment. Where insurers recoil in the face of climate change, consumers will encounter acute affordability issues accompanied by huge holes in this societal safety net. But insurers' efforts to date demonstrate that market-based mechanisms can support greenhouse-gas emission reductions and adaptation to otherwise unavoidable impacts." Mills (2009) also notes "the insurance sector, which is the world's largest industry in terms of revenue, could be a major partner in managing, spreading, and providing incentives for reducing natural catastrophe risk and, thereby, could promote adaptation to climate change." While financial relief is the general tool after a catastrophe, the insurance industry may aid society in adapting to increasing risk and may enhance economic resilience to catastrophes by providing incentives for risk reductions (Mills and Lecompte, 2007). Jacques Attali, former president of the European Bank for Reconstruction and Development, went further in his assessment of the future: "Insurance companies will insist that businesses comply with the norms decreed by such agencies in order to reduce climatic disturbances and the damage caused by natural distasters that might follow in their wake" (Attali, 2006). In a recent development, an insurance company is suing the city of Chicago for failing to prevent flooding related to climate change, in what experts suggest could be a landmark case (Lehmann, 2014). A trio of global initiatives has aggregated 129 insurance firms from 29 countries to support climate research and develop adaptation techniques to climate change, but only one in eight companies currently has a formal strategy to adapt to climate change (Mills, 2012).

Brian Fuchs, University of Nebraska–Lincoln

Grasshopper infestation in a drought-stressed corn field east of Lincoln, June 2002. Increased drought frequency and warmer winters associated with climate change will increase pest infestation in Nebraska.

CHAPTER 8

THE SCIENTIFIC CONCENSUS AND DEBATE

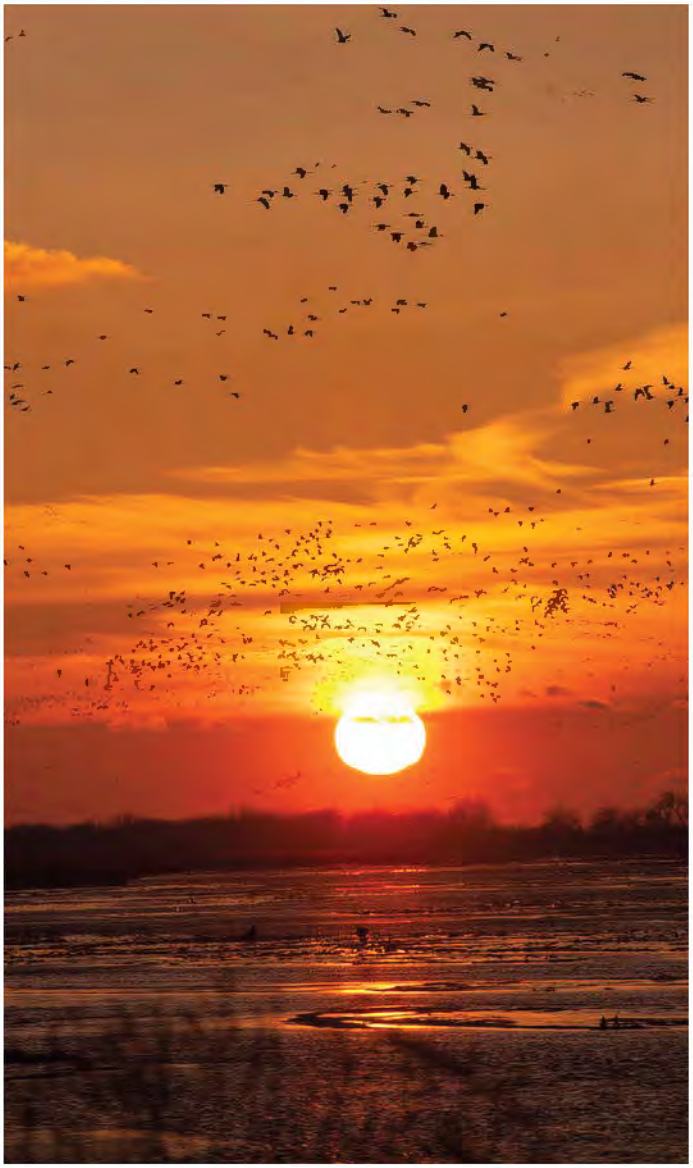
Is There a Debate within the Scientific Community?

The short answer here is "no", at least certainly not among climate scientists—that is, those scientists who have actual expertise in the study of climate and climate change. For more than a decade, there has been broad and overwhelming consensus among the climate science community that the human-induced effects on climate change are both very real and very large. The debate in 2014 is restricted to precisely how these changes will play out—for example, what impact reduced Arctic sea ice will have on mid-latitude storms and weather.

It is true that a number of Ph.D.-level scientists have spoken out very publically and vocally against human impacts on climate. It is important to realize that in virtually every one of these cases, the Ph.D. is in a field of study not related to climate science. Although they may be very distinguished in their own field, they have no expertise in climate and climate change. Therefore, they are just stating their own personal opinion. When genuine climate scientists discuss these issues, however, they are giving you their informed professional judgment based on their scientific expertise.

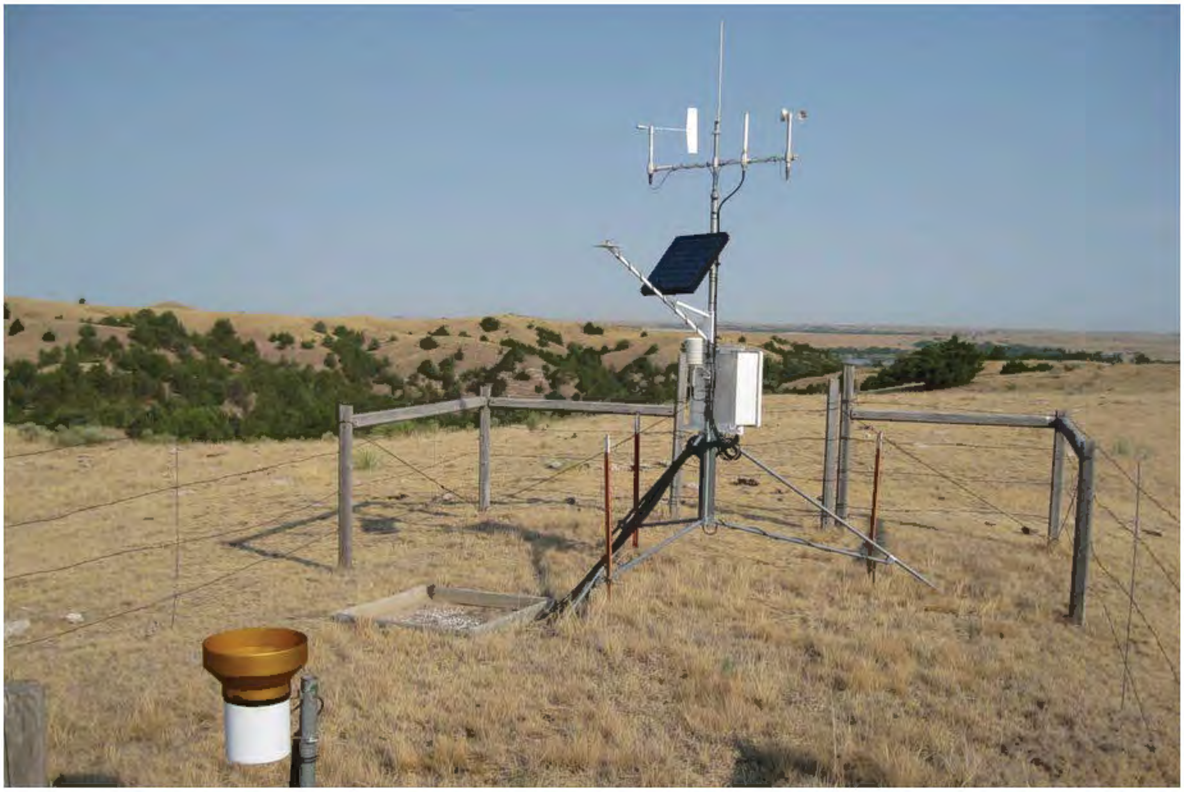
The fact that climate change has become a highly politicized issue has no bearing whatsoever on the reality of human-induced climate changes. Politics—or personal beliefs—are not part of the evidence-based scientific process, and we cannot simply legislate away the reality of human impacts on the climate system. However, we can develop policies that mitigate the magnitude of human-induced climate change and help society adapt to the impacts that are inevitable.

Many of these political pundits of climate change often make the claim that the climate models are too uncertain to be trusted. They then state that therefore the human-induced effects on climate change do not exist. In addition to the obvious logical fallacy of concluding uncertainty about an effect implies the effect must not exist, these pundits fail to recognize that we do not need climate models to tell us that climate change is real and happening rapidly all around us. The evidence is overwhelming in the atmosphere, in the ocean, on land, and where there is still ice (at least for now). We only use the models to attempt to simulate these changes and project them forward through the remainder of this century. Indeed, by far the largest source of uncertainty is in the greenhouse gas emission scenario that will unfold in coming decades. This in turn has *nothing* to do with climate models, and everything to do with human behavior. In other words, are we as individuals, nations, and the world as a whole willing or not to do something about global warming?



NEBRASKAland Magazine/Nebraska Game and Parks Commission

The sun sets over thousands of Sandhill Cranes along the Platte River in central Nebraska.



Glen Roebke, University of Nebraska–Lincoln

Automated Weather Data Network (AWDN) station near Ogallala at the Cedar Point Biological Station. This network and others around the state are essential for monitoring current weather conditions and long-term trends in temperature and precipitation.

Brian Crabtree, Nebraska Weed Control Association

Phragmites, an invasive species, grows uncontrolled along the Missouri River. Invasive species will increase in Nebraska as a result of changing temperatures and increases in precipitation variability.

CHAPTER 9

SUMMARY

Observational evidence clearly indicates that our planet is warming, with the amount of warming varying regionally because of differing climate controls. Human activities, particularly those causing increasing concentrations of greenhouse gases (GHGs) in the atmosphere and land use changes, are the principal causes for these observed changes. While governments work to place controls on the emissions of GHGs, in particular CO_2, in order to mitigate a greater warming of our planet, we must continue to adapt to the changes that have occurred and are projected to occur through the twenty-first century and beyond.

Current and projected changes in temperature will have positive benefits for some and negative consequences for others, typically referred to as winners and losers. However, the changes in climate currently being observed extend well beyond temperature and include changes in precipitation amounts, seasonal distribution, intensity of precipitation events, and changes in the form of precipitation (for example, less snowfall. Changes in the observed frequency and intensity of extreme events are of serious concern today and for the future because of the economic, social, and environmental costs associated with responding to, recovering from, and preparing for these extreme events in the near and longer term.

Nebraska's climate is highly variable over a range of timescales from a few years to decades or longer. Recent droughts, heat waves, and floods provide evidence of that variability. Since the latter decades of the twentieth century, temperature observations for the state have shown an upward trend. Annual precipitation has increased for some areas, especially the eastern portion of the state, but when coupled with increasing temperatures and hence evaporative demand, available water supplies have not kept pace. Our frost-free season has increased drastically by ten days to two weeks and is expected to increase further in the coming decades, posing both opportunities and new challenges for the future for agriculture and many other sectors. A particular concern is the projected increase in the occurrence of high temperature stress days (days > 100°F) and the effect it will have on the demand for our precious water resources, available soil moisture, natural and managed ecosystems, and groundwater recharge. The impact of declining snowpack in the states to the west also has major implications for surface water supplies across Nebraska.

The ability of key sectors of our state to adapt to future changes in our climate and a consequent increase in climate extremes is a major concern. Adaptations for the future will require the application of a broader range of strategies and greater innovation. For agriculture, the backbone of Nebraska's economy, the key messages for U.S. agriculture from the Third National Climate Assessment report (2014) clearly state the primary challenges that will affect agriculture and our state in the future. These include:

1. Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops and livestock.

2. Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.

3. Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.

4. The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.

5. Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure that the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.

6. Climate change effects on agriculture will have consequences for food security, both in the United States and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.

We concur with the key messages of the National Climate Assessment report regarding the challenges for agriculture. Nebraska will not be able to avoid the impacts associated with climate change for agriculture and other key sectors without strategic actions now and in the future. It is also clear that we need to acknowledge these impending changes to our climate and begin to address them through a constructive dialogue with all stakeholder groups.

We also note that the implications and potential impacts associated with observed and projected changes in climate will be closely associated with the management practices employed by managers associated with these specific sectors. For example, the impacts of projected changes in climate on the productivity of a specific farm will be dependent on the ability of that producer to adapt to these changes as they occur and the producer's access to new and innovative technologies that facilitate the adaptation process. These early adapters will be better able to cope with changes as they occur.

The expert commentaries included in this report address many of the impending changes and raise serious concerns about how projected changes in climate will impact Nebraska. These commentaries also outline some of the actions that we should take to adapt to the changes. The commentaries provide a starting point for the discussion with stakeholders regarding possible adaptation measures for the future in each of these sectors. Twelve states have prepared climate change adaptation plans and three states are in the process of preparing plans. Information on these plans is available from the Georgetown Climate Center (http://www.georgetownclimate.org). The approach taken in preparing these plans could serve as a model for Nebraska.

This report documents many of the key challenges that Nebraska will face as a result of climate change. Imbedded in each of these challenges are opportunities. A key takeaway message from the report is that, with this knowledge in hand, we can identify actions that need to be implemented to avoid or reduce the deleterious effects of climate change for Nebraska. Action now is preferable and more cost effective than reaction later.


Dana Divine, Nebraska Weed Control Association

A saline wetland in Lancaster County, Nebraska.

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APPENDIX

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School of Natural Resources
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

STATE OF NEBRASKA

NEBRASKA EMERGENCY MANAGEMENT AGENCY
Daryl L. Bohac
Director
2433 NW 24th Street
Lincoln, Nebraska 68524
Phone (402) 471-7421

Pete Ricketts
Governor

August 5, 2016

Senator Tyson Larson & Senator Ken Haar
Co-Chairs, LR455 Special Committee
State Capitol Building
Lincoln, NE 68509

Dear Senators Larson & Haar:

The following is in response to your inquiry regarding the inventory of state agency activities related to climate change & resiliency.

1. NEMA's Hazard Mitigation unit is engaged in climate resiliency activities as they are related to the natural weather-related hazards that occur across our state. As an emergency management agency our main focus is to assist communities before, during and after a disaster.

   The hazard mitigation unit's primary focus is to assist communities to reduce their hazard risk profile. This is accomplished through state & local hazard mitigation planning and mitigation projects, such as outdoor warning sirens, safe rooms and flood mitigation endeavors, just to name a few activities. In the emergency management world "mitigation" is reducing the risk of damage and potential loss of life associated with a man-made or natural hazard, such as tornadoes, flood, hail and other weather related anomalies.

2. NEMA assists with many planning efforts, both on the state and local level. Our mitigation team completes a State Hazard Mitigation Plan review every five years. As of March 2016, FEMA requires that climate resiliency be included in that review. Our current state plan was approved in May of 2014.

   The State plan provides a template for local multi-jurisdictional mitigation plans throughout the state as well as offers suggestions for standards of risk protection. The hazard analysis addresses both the vulnerability and probability of a hazard event while the strategic actions are directed at mitigating the effects of these hazards

3. NEMA continually coordinates with other state & federal partner agencies on a variety of topics related to emergency management. The mitigation unit is prominently engaged with these state and federal partners coordinating efforts related to climate resiliency efforts and planning.

The agency has a representative on the Climate Assessment Response Committee (CARC), which is led by the State's Department of Agriculture.

NEMA's mitigation staff also regularly works with organizations such as the National Drought Mitigation Center, the National Weather Service, the State Climate Office who are best informed regarding the most current statistics and trends related to the state's natural hazards.

NEMA's staff is passionate about assisting the communities across our state to be more prepared for the next disaster event. We know that to best accomplish this goal we must address all hazards in their worst extreme. As the adage goes, "Prepare for the worst and hope for the best." Abiding by this mantra we are able to affect greater change in reducing the risk profiles of our communities and therefore enabling our citizens to bounce back quicker after a disaster strikes. Our agency cannot stop the next disaster from happening, but we will do all we can to reduce the effects of an event on our state, its communities and our citizens.

Sincerely,

Bryan Tuma
Assistant Director

Bryan Tuma
Climate Assessment Response Committee (CARC)
Confirmation Hearing – January 22, 2019 at 1:30 PM
Key Concepts or Talking Points

The following concepts would be emphasized:

NEMA, like all other emergency management agencies must rely on stakeholder engagement strategies to build a comprehensive emergency management program focused on the concepts of preparedness, response, recovery, planning, and mitigation.

These activities require continued emphasis on building relationships with key professionals, organizations, and stakeholder groups who can provide information and perspective on the issues.

NEMA views the activities of the CARC to be especially useful to assist with the evaluation of long-term, systemic change in weather patterns that may influence planning, response, recovery, and mitigation issues.

The Nebraska Emergency Management Agency embraces the efforts of the CARC to provide timely and systematic data collection, analysis, and dissemination of information about drought and other severe climate occurrences to the Governor and other interested persons.

This information is inherently critical to the mission of NEMA to address response and recovery activities based on the analysis of risk, impact, and consequence associated with natural disaster phenomenon.

The CARC represents a significant resource for NEMA and other emergency management agencies in the state to assess and evaluate the threat potential from severe weather disasters.

Identifying the threat potential associated with specific weather patterns enhances the efficiency and effectiveness of response and recovery measures to be considered.

This is especially useful to address resource allocation and mitigation strategies that help reduce risk to property and life.

NEMA views the role of the CARC to be especially useful in the development of future mitigation strategies. Mitigation activities are intended to reduce the impact of future disasters.

This can be achieved by moving infrastructure out of harm's way, or hardening infrastructure to withstand the impact of severe weather events.

Warning devices, construction of shelters, building levees, or investing in flood control projects represent some of the mitigation strategies that can help reduce future disaster costs.

Eligibility requirements for hazard mitigation funding require applicants to have plans in place prior to the disaster event.

Planning at the local level must compliment the State Hazard Mitigation Plan.

The information from the CARC can assist all entities with hazard mitigation planning strategies.

A historical overview of Nebraska disaster data indicates the state has experienced 64 federally declared disasters since 1964. Nebraska has experienced nearly 60% of those disaster events in the last 20 years. Evaluating future climate issues is essential to addressing the threat and risk to our communities and economy posed by severe weather events. Preparedness activities at the state and local level must evaluate threats and hazards in the development of response, recovery, and mitigation measures.

Recently, Congress passed the Disaster Recovery and Reform Act to significantly enhance resources to states impacted by federal disaster declarations. While many of the policy requirements associated with the new legislation are currently being addressed by FEMA, it is clear that states will be allocated more funds to cover the administrative costs associated with the Public Assistance and Hazard Mitigation recovery programs. More emphasis will be focused on hazard mitigation programming based on the historical cost/benefit analysis which demonstrates a six dollar return on investment for every dollar dedicated to hazard mitigation projects. NEMA would expect the agency to have greater reliance on information, technical advice, and guidance from groups or organizations such as the CARC to assist in developing the hazard mitigation strategies in the future.

CARC Meeting Minutes (Draft)
Wednesday, May 20, 2015
10 a.m. 901 Hardin Hall East Campus
Meeting called to order at 10:04 a.m.

In Attendance:
Committee Members: Bobbie Kriz-Wickham (Chair), Nebraska Department of Agriculture; Barb Cooksley, Rancher; Mary Baker, Nebraska Emergency Management Agency; Dr. Mike Hayes, National Drought Mitigation Center; Ashley Mueller, University of Nebraska Cooperative Extension; Dr. Matt Joekel, UNL Conservation and Survey Division

Staff and Audience: Mark Svoboda, National Drought Mitigation Center; Brian Fuchs, National Drought Mitigation Center; Al Dutcher, State Climatologist; Dean Groskurth, National Agriculture Statistics Service; Eric Zach, Nebraska Game & Parks Commission; Doug Klein, Farm Service Agency; Barb Mayes Boustead, National Weather Service-Omaha; Neil Dominy, USDA-Natural Resources Conservation Service; Marcia Trompke, Central Nebraska. Public Power and Irrigation District; Scott Sprague, Department of Health & Human Services-Division of Public Health

Committee Chair, Bobbie Kriz-Wickham, opened the meeting with self-introductions as this the first CARC meeting under new Governor Peter Ricketts and there are several new committee members.

Mark Svoboda, Water Availability and Outlook Report, National Drought Mitigation Center –

At the last CARC meeting, held June 24, 2014, there was a concern of drought starting to take hold in southwest and central Nebraska connecting to already poor conditions in Kansas, Oklahoma and Texas. However, recent rains have mitigated severe drought in a large portion of those areas, and while there is still caution, the outlook is much better than a year ago.

Current Drought Conditions in Nebraska and the region

National summary -Last week's (May 12, 2015) U.S. Drought Monitor Map shows some mild to moderate drought areas beginning in the upper Midwest with a "highway" running through central and southwest Nebraska connecting it to the drought areas that run through parts of Kansas, Oklahoma and into Texas. However, due to recent heavy rains as a result of moisture from the Gulf of Mexico, much of the severe drought areas in that region of the country have shown remarkable recovery.

The severe to extreme drought in California continues to linger and worsen and is extending into Washington and Oregon.

High Plains Region – Currently 7% of the region is in severe drought, with 31% of the region in any type of drought classification. Most of that 31% is in the D1 category, the lowest drought classification. There has been significant improvement over the past few weeks with a drop in overall drought classification in the region of 13% the past week.

Nebraska – In Dec. of 2014, there was a large area of abnormally dry conditions in much of southwest and parts of central Nebraska. Drought conditions crept into the area and extended to the northeast with significant departure from normal precipitation levels dating back to October 2014 in that area of the state. Recent rains helped alleviate the spring drought condition, and there is only 20% of the state in class 1 drought conditions at this time. The drought strip that runs from the southwest corner of the state, through central Nebraska, into the northeast section, still presents a concern but is in the positon for recovery if rains would arrive in the near future.

For the year, precipitation totals in Nebraska range from 6 to 9 inches above normal in some heavy rainfall areas (primarily in the southeast) to below normal precipitation in the past 30 days for that corridor of dry area that runs form the southwest to the northeast of the state.

Soil moisture in most of areas of the state has shown overall improvement, especially in the top 1 meter of the top soil, however there are concerns of drier conditions in the deeper soil columns in the areas of the state that have had drier overall conditions.

The May 1, 2015 Spring and Summer Streamflow Forecasts showed a decrease from the previous year based on snowpack in the Rocky Mountains. Last year the snowpack was very good for the areas that feed the Missouri, North Platte and South Platte river basins, but the outlook is for lower flows this spring and summer. While there is concern, it is not an extreme condition.

*The U.S. Monthly and Seasonal Drought Outlook, r*eleased in April, showed concern for increasing drought in southwest Nebraska with the corridor running through central into northeast Nebraska. However, rains in May are expected to provide a more optimistic outlook when the new maps are released on May 21, 2015.

In looking at sea surface temperature anomalies for the Pacific and Indian Oceans, the water temperatures have been running 1 to 3 degrees warmer than normal which is considered significant. These types of anomalies do have a big impact on weather in the United States. Forecasters continue to be bullish on the outlook for El Nino persisting into the summer through the end of this year.

It is rare to have an El Nino event in the summer months. Because of the lack of historical data, it is very difficult to predict what effect the event will have on weather conditions in the next several months. We do know that Nebraska typically sits “on the bubble” during El Nino, meaning it will tend to have an equal chance of above or below temperatures and above or below normal precipitation.

<u>Summary</u>
We have had a good/great late spring rainfall-wise across most of the region:

- 150-200% of normal precipitation over the past 30 days and slightly cooler;
- Too much moisture in some places…leading to flooding along with recent severe weather outbreaks;
- 34.6% of the contiguous U.S. is currently in drought (D1 or worse) as of 5/12/2015
    - This time last year it was at 38.1%
    - Down nearly 6% Year-to-Date (28.7% on Dec. 30, 2014);
- Current Drought Monitor for Nebraska shows 20% of the state in drought (D1 only) up from 0% in January 1, 2015;
- The Climate Prediction Center's Seasonal Drought Outlook calls for improvement or removal of drought across the Central and Southern Plains by the end of July with some exceptions in south central Nebraska;
- Large fetch of moisture from the Pacific region and Gulf of Mexico has led to the recent favorable rains;
- Despite early-period wetness, precipitation for the upcoming wet season is enough of a question mark that drought persistence is forecast in southern Nebraska and eastern Kansas; and
- There is an approximately 90% chance that El Niño will continue through the Northern Hemisphere in summer 2015 and a greater than 80% chance it will last through 2015.

Brian Fuchs, National Drought Mitigation Center Report

<u>Nebraska Water Supply Update</u>

Lake McConaughy has 1.359 million acre-feet in storage (77.9% of capacity). Inflows have increased recently and ranged from 1,100 cubic feet per second to 3,251 cubic feet per second, which is above normal for historical inflows for this time of year.

Snowpack in the upper North Platte River Basin is 62 percent of normal and 39 percent of normal in the lower basin with declining values, a few weeks ahead of normal. Snowpack in the South Platte River Basin is at 90 percent of normal.

Nebraska has been taking advantage of the large amounts of water coming into the Platte River and pushing it into irrigation canals and storage facilities. Being able to store the water is occurring earlier than normal and that is a good sign. Look for another month of this good push of water, but it will be based on rains in the foothills of Colorado.

The spring and summer streamflow forecasts as of May 1, 2015, show moderate to good flows from the northern to eastern range of the Colorado Rockies. However, flows from western range are expected to be very poor, further adding to the extreme drought conditions in the western United States.

The USGS 14-day average national streamflow map shows that conditions are much improved in Texas, Oklahoma, Kansas and eastern Nebraska. In looking at the 14-day streamflow for Nebraska, the Republican River continues to have low stream flows and is showing signs of stress. However, the rest of the stream flows around the state are normal to above normal.

Conservation pools of the Republican River Basin reservoirs have improved the past 11 months. Hugh Butler is at 28.6% compared to 10.7%, Enders is up to 24.2% from 21%, Harry Strunk is at 100% compared to 62.7% and Swanson Reservoir has increased to 40.8% compared to 27.8%.

The conservation pool at Harlan County Reservoir is currently at 60.3% full, up from 52.7% last June. There is 189,484 acre-feet of storage at Harlan County compared to 156,838 a year ago. Historical storage for this time of year is 299,153 acre-feet.

Summary

Hydrologic conditions across the state are in good shape going into summer;

- Lake McConaughy is 8.6 feet higher from last June. The inflows at the lake have increased over the past few weeks as the influx of good rains and earlier runoff have combined for more available water going into the system;

- The overall storage of water in the Republican River Basin and Harlan County Reservoir has improved in the past 11 months; and

- The overall water supply situation for Nebraska is not problematic at this time, except for some flooding in isolated portions of the state.

Current Weather Conditions for Nebraska

Temperatures in Nebraska have been above normal for the last 60 days, however if you break that down and look at just the last 30 days, temperatures have been 2 to 3 degrees below normal in the southeastern and Panhandle portions of the state, but continuing slightly warmer in the areas that have had dry to near drought conditions.

The largest rainfall amounts have taken place in parts of southeast Nebraska and in portions of the Panhandle. The areas of the state that have been dry are still lacking rains and continue to have warmer temperatures.

In the Panhandle and north central Nebraska, wet snow has continued to fall this past week following up the heavier snows in early May. The moisture has been welcomed.

For the year, the drier areas of the state are running 2 to 3 inches below normal precipitation due to the dry winter, especially in March.

There are growing concerns in northeast Nebraska regarding soil moisture. Some areas are 6-to-7 inches below normal in soil moisture, especially in the deeper column of the soil profile. The topsoil has enough moisture for good planting conditions, according to some producer reports.

Looking ahead to the rest of May, June and July, Nebraska has equal chances for lower or higher than normal temperatures and precipitation, which is typical in an El Nino period, which currently exists.

El Nino has a high probability of extending into June, July and August and possibly beyond. Because it is rare to have a summer El Nino, there is a small sample of historical data to provide trends. However, the trends that have been recorded would give some indication that Nebraska may have below normal temperatures and above normal precipitation in the western portion of the state, and above normal temperatures and below normal precipitation in the eastern portions of the state.

Additional Discussion

Al Dutcher, State Climatologist, commented that much of the state's corn crop could now use some warmer and drier weather in order to begin to emerge and mature properly. There is concern in some parts of the state that the soybeans that have been planted may be damaged due to sitting in very moist soil for a long period of time.

Dutcher mentioned, that in his travels around eastern Nebraska, he witnessed some significant erosion damage with large crevasses appearing in some fields. He also mentioned that there were some fields that have extremely large pieces of debris (primarily trees) that had been carried onto the area by heavy rain and subsequent flooding.

Dutcher added it is difficult to gauge how much of the flooded corn ground could still be replanted this spring. It will depend on current weather conditions. He is concerned that farmers may get in a rush to finish planting which could create compaction problems.

Dutcher also expressed concern about harvest season. With some corn being planted very early, and some still to being planted, one portion of the crop will need hot dry weather for harvest and the other portion will require more moisture to finish growing.

In conclusion Dutcher said that it would be typical to get some continued wet weather for a few more weeks but that can also be followed by very hot and dry conditions which will take up the subsoil moisture very quickly.

Dean Groskurth with the National Agriculture Statistics Service reported that the May 1 USDA wheat forecast for Nebraska was for a statewide average of 40 bushels an acre, which would be 9 bushels an acre or 10 percent below last year. However, he pointed out the forecast does not account for the recent snow in a large portion of Nebraska's wheat-growing areas, the impact of which is yet unknown. Meanwhile the May 1 haystock figures for Nebraska showed a 9% increase over the haystock figures a year ago.

Groskurth reported that while the number of acres of planted corn (85%) in Nebraska was close to normal for this time of year, the number of planted soybean acres (41%) was far below last year's 61% at this time of year.

Doug Klein, Nebraska Farm Service Agency, reported that while there had been some damage to crops in Nebraska due to recent flooding (2-3% in any one county) that amount was far below the level required (30% in one crop per county) to request a disaster declaration from the U.S. Secretary of Agriculture.

Bobbie Kriz-Wickham, CARC Chair, Nebraska Department of Agriculture, told the Committee she would be providing a report of the meeting to Governor Pete Ricketts. The report would include an overview of the climatic conditions and water supplies in the state. She said she would use the latest maps and statistics that were to be released on May 21.

Mike Hayes, National Drought Mitigation Center, mentioned that Don Wilhite from the University of Nebraska School of Natural Resources is organizing roundtable discussions around the state to discuss climate change issues. The discussion will cover six different topics including food and water, forestry and fire, urban systems and rural communities, wildlife and eco systems and energy. The roundtables will take place in September, October and November. Mike will share details with CARC once they are finalized.

Committee Member, Barb Cooksley suggested CARC consider reviewing and updating the current drought plan which was last revised in 2000.

Chair Kriz-Wickham mentioned that subcommittee volunteers would be needed in order to undertake such a project. She will solicit for volunteers soon.

No future meeting date was set but tentative plans would be for a meeting to be held this fall. However, changing climatic conditions may warrant the need for a meeting sooner.

Meeting adjourned at 11:43 a.m.

CARC Meeting Minutes (Draft)
Wednesday, May 20, 2015
10 a.m. 901 Hardin Hall East Campus
Meeting called to order at 10:04 a.m.

In Attendance:
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Additional Discussion

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Dutcher mentioned, that in his travels around eastern Nebraska, he witnessed some significant erosion damage with large crevasses appearing in some fields. He also mentioned that there were some fields that have extremely large pieces of debris (primarily trees) that had been carried onto the area by heavy rain and subsequent flooding.

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Dutcher also expressed concern about harvest season. With some corn being planted very early, and some still to being planted, one portion of the crop will need hot dry weather for harvest and the other portion will require more moisture to finish growing.

In conclusion Dutcher said that it would be typical to get some continued wet weather for a few more weeks but that can also be followed by very hot and dry conditions which will take up the subsoil moisture very quickly.

Dean Groskurth with the National Agriculture Statistics Service reported that the May 1 USDA wheat forecast for Nebraska was for a statewide average of 40 bushels an acre, which would be 9 bushels an acre or 10 percent below last year. However, he pointed out the forecast does not account for the recent snow in a large portion of Nebraska's wheat-growing areas, the impact of which is yet unknown. Meanwhile the May 1 haystock figures for Nebraska showed a 9% increase over the haystock figures a year ago.

Groskurth reported that while the number of acres of planted corn (85%) in Nebraska was close to normal for this time of year, the number of planted soybean acres (41%) was far below last year's 61% at this time of year.

Doug Klein, Nebraska Farm Service Agency, reported that while there had been some damage to crops in Nebraska due to recent flooding (2-3% in any one county) that amount was far below the level required (30% in one crop per county) to request a disaster declaration from the U.S. Secretary of Agriculture.

Bobbie Kriz-Wickham, CARC Chair, Nebraska Department of Agriculture, told the Committee she would be providing a report of the meeting to Governor Pete Ricketts. The report would include an overview of the climatic conditions and water supplies in the state. She said she would use the latest maps and statistics that were to be released on May 21.

Mike Hayes, National Drought Mitigation Center, mentioned that Don Wilhite from the University of Nebraska School of Natural Resources is organizing roundtable discussions around the state to discuss climate change issues. The discussion will cover six different topics including food and water, forestry and fire, urban systems and rural communities, wildlife and eco systems and energy. The roundtables will take place in September, October and November. Mike will share details with CARC once they are finalized.

Committee Member, Barb Cooksley suggested CARC consider reviewing and updating the current drought plan which was last revised in 2000.

Chair Kriz-Wickham mentioned that subcommittee volunteers would be needed in order to undertake such a project. She will solicit for volunteers soon.

No future meeting date was set but tentative plans would be for a meeting to be held this fall. However, changing climatic conditions may warrant the need for a meeting sooner.

Meeting adjourned at 11:43 a.m.

CARC Meeting Minutes (DRAFT)
Monday, Nov. 19, 2018
901 Hardin Hall, UNL East Campus

Meeting called to order at 9:34 a.m.

In Attendance:
Committee members or representatives: Amelia Breinig (chair), Nebraska Department of Agriculture; Mark Svoboda, National Drought Mitigation Center; Dr. Shuhai Zheng, Nebraska Department of Natural Resources; Matt Joeckel, UNL Conservation and Survey Division; Rick Rasby, UNL Extension; Carl Sousek, crops farmer; Judy Martin, Nebraska Department of Health and Human Services; Bryan Tuma, Nebraska Emergency Management Agency and Barb Cooksley, rancher.

Staff and Audience: Brian Fuchs, National Drought Mitigation Center; Martha Shulski, Nebraska State Climatologist; Steve Roth, Nebraska Department of Agriculture; Dean Groskurth, USDA-NASS (National Agricultural Statistics Service); Aaron Hird, USDA-NRCS (Natural Resources Conservation Service); Eric Zach, Nebraska Game and Parks; Ed Holbrook, Nebraska Energy Office; Rezaul Mahood, High Plains Regional Climate Center; Ginger Willson, Nebraska Senator Ben Sasse's office; Tyler Williams, UNL Extension; Donny Christensen, Nebraska Emergency Management Agency; Ashton Tennis, Nebraska Emergency Management Agency; Doug Klein, USDA-Farm Service Agency; Marcia Trompke, Central Nebraska Public Power and Irrigation District; Brian Barjenbruch, National Weather Service; Hallie Bova, National Weather Service and Suzanne Fortin, National Weather Service.

Committee Chair Amelia Breinig opened the meeting stating that CARC follows provisions in Nebraska's Open Meetings Act and a copy of the act was available for review. She also had copies available of the affidavits of the public notices published in the Lincoln Journal Star and Kearney Hub newspapers on November 12, 2018.

Breinig is the new assistant director at the Nebraska Department of Agriculture and was designated by Director Steve Wellman to chair CARC on behalf of the department.

Minutes from the June 4, 2018 CARC meeting were accepted by the committee as presented.

Reports were provided as follows:

Nebraska Drought Conditions and Water Supply Update
Presented by Brian Fuchs, National Drought Mitigation Center
Past/Current Climate & Drought Report
In reviewing U.S. Drought Monitor maps for Nebraska, Fuchs pointed out that there was a small area of abnormally dry conditions in the panhandle a year ago (November 21, 2017). On May 29, 2018, the map showed a portion of southeast Nebraska had developed abnormally dry to D1 conditions, but the most recent map (November 13, 2018) shows Nebraska as being drought free. In fact, the state has been drought free since early September of this year.

In looking at the High Plains Region (North Dakota, South Dakota, Wyoming, Nebraska, Colorado and Kansas) there has been a three to four drought-class improvement in Missouri and Kansas the past three months.

The current maps indicate that 20 percent of the region remains in drought, most of that in Wyoming and Colorado. Parts of Colorado have extreme to exceptional drought conditions.

From 2016 to present, Nebraska had just a small area of severe drought in 2017. Otherwise, there has not been any severe, widespread drought since the extreme drought conditions in 2012 into 2013.

Fuchs mentioned that Nebraska has gone into a wetter than normal pattern the past six years, but there have always been droughts in Nebraska. Droughts tend to come in cycles and he expects a drought will be coming at some point.

Nebraska has experienced below normal temperatures over the past 30 and 60 days, as well as since the beginning of the calendar year. It is not something the state has experienced in recent years as temperatures had been trending warmer.

In the last 30 days, much of the High Plains Region has seen below normal precipitation. However, the previous 30 days was much above normal, which made up for the current dry conditions in the region.

For the calendar year, most of Nebraska has had above normal precipitation. There have been some pockets of dryness in the far west panhandle.

The Soil Moisture Model indicates that much of Nebraska has surpluses in many areas of the state. This is for the first one meter of top soil.

The U.S. Seasonal Drought Outlook from the National Weather Service indicates that Nebraska is not expected to develop any drought conditions in the state from now through February.

The Drought Outlook does expect drought conditions to develop or continue in northcentral North Dakota, central South Dakota, the southern border of Wyoming and most of Colorado.

Fuchs provided this climate/drought summary:

- Cooler than normal conditions have dominated the state and region so far in 2018 with Nebraska averaging about 1-2°F below normal.
- Almost the entire state of Nebraska has recorded above normal precipitation for this year so far, with areas of northcentral Nebraska 8-12 inches above normal.
- Over the last 60 days, the entire region has been below normal for temperatures with the northern portions of the Plains 4-6°F degrees below normal and the southern portions 2-4°F below normal.
- Nebraska is drought free and has been since early September. The last time Nebraska was drought free was at the end of June 2017.
- Drought has not been a widespread issue in Nebraska for the last several years with very little severe drought since the summer of 2014.
- The seasonal drought outlooks do not show drought conditions developing in Nebraska through the end of February 2019.

<u>Nebraska Water Supply Update</u>
When looking at the state water supply, Fuchs said he likes to start with Lake McConaughy since it is the largest reservoir in Nebraska.

Lake levels were at or near normal for this time of year, according to the Central Nebraska Public Power and Irrigation District (CNPPID). In the past few months, Lake McConaughy has gained some water supply.

Inflows to the lake are slightly below the mean in average for this time of year, but Fuchs said it was nothing to be concerned with at the present time.

He mentioned that some water from the lake had been pushed down the Platte River as part of the allocation for the Nebraska Environmental Trust account needed for the whooping crane migration.

Fuchs presented news releases from CNPPID regarding conditions at Lake McConaughy. Those releases will be posted as part of Fuchs' PowerPoint presentation on the CARC website.

In areas of the U.S. where dry or drought conditions have existed, streamflows have been below or much below normal. This includes the four corners area (Utah, Arizona, Colorado and New Mexico), as well as parts of Kansas, Oklahoma and Texas. Steamflows in Nebraska have been mostly normal or slightly above normal. The Republican River Basin in the southwest part of the state typically runs lower this time of year but actually is currently above typical levels.

The conservation pool and storage at the Harlan County Reservoir were higher than this time a year ago.

Fuchs provided this water supply summary:

- Lake McConaughy is currently 80.2 percent of capacity, which is lower than in June 2018 (last CARC meeting) and slightly higher compared to levels in November 2017.
- The Republican River basin reservoirs are lower than in June as water levels dropped due to the irrigation season and are stabilizing with fall diversions into the systems.
- Harlan County Reservoir is holding about 22,450 acre-feet less water now than in June 2018.
- Harlan County is holding about 16,000 acre-feet more water now than at this time last year and is about 21,000 AB above average for this time of year.
- All reservoir levels and storage should hold steady until the spring run-off.

Fuchs' PowerPoint presentation will be posted on the CARC website.

Nebraska Climate Update
Presented by Martha Shulski, Nebraska State Climatologist

In recapping the spring conditions for Nebraska, Shukski noted that Nebraska had its second coldest April on record, followed by its fourth warmest May. Dry conditions were seen in portions of southeastern and southcentral Nebraska, while a mid-April blizzard intensified planting delays in northeastern and northcentral portions of the state.

The warm May that continued into June, allowed for crops to catch up from delayed planting as growing-degree days accumulated during the two-to-three-month period.

The rest of the summer saw varying conditions throughout the state, which included heavy rains at times but also heat stress in some areas. Timely rains in the middle to late part of the growing season provided relief to heat- stressed crops.

Meanwhile, irrigation demand was well below normal in Nebraska due to overall above normal rainfall.

September started off warm and dry, but cooler and wetter conditions set in as the month came to an end. This did inhibit harvest to some degree.

October was a month of wet and dry cycles including some significant snow events in some parts of the state. The conditions lent itself to delays in harvest but activity did take place during the dry periods.

November kicked off with similar wet and dry cycles as was seen in October. Harvest continued to lag behind but was still making progress.

Shulski noted that even with the wet conditions this fall in Nebraska, the state experienced minimal compaction and rutting issues during harvest. That was not the case in the Eastern Corn Belt where much more precipitation had fallen.

Dry conditions have been slowly building across the western half of Nebraska the past three months. There had been concerns over the condition of the winter wheat crop in the southern half of the panhandle beginning in October. However, mid-October snowfall improved the crop conditions significantly.

The climate outlook for Nebraska for the rest of November was for greater chances of above normal precipitation and below normal temperatures. The National Weather Service winter (December, January, February) outlook for Nebraska is calling for a greater chance of above normal temperatures for the period, while there are equal chances for above or below normal precipitation.

The U.S. is currently in what is defined as neutral conditions. However, with warmer temperatures in the Pacific Ocean, there is an 84 percent chance of an El Nino event developing. The current prediction is for the El Nino to develop over the winter and continue through spring. This El Nino is expected to be a weak event.

Shulski pointed out that classic El Nino trends can be heavily impacted by other patterns, and that each El Nino is unique.

There is no clear evidence at this time how the El Nino will impact Nebraska weather in the coming months.

There was discussion in the meeting on how upcoming winter weather patterns may affect snowpack in the Rocky Mountains. This is important to Nebraska since several river basins in the state depend on mountain runoff for adequate surface water supply.

It appears the snow pack in the mountains is off to a good start but too early to predict how much snow pack will occur this winter. Much will depend if snowfall occurs higher in the mountains where it can accumulate or at lower elevations where it could melt and runoff immediately.

Shulski also discussed soil moisture in Nebraska going into the winter. She said while overall the state is starting off with a pretty good profile, soil moisture amounts tend to be very localized due to differences in soil and local precipitation amounts.

Shulski's PowerPoint presentation will be posted on the CARC website. It includes additional weather resources that can be accessed on the internet.

Nebraska Hay Stocks and Crop Condition Report
Presented by Dean Groskurth, USDA-NASS (National Agricultural Statistics Service)

Groskurth said that while corn production estimates nationally were down slightly in the USDA-NASS November report, overall U.S production is still expected to be the second largest on record. The estimate for national average yield of 178.9 bushels per acre would be a new record.

The estimates for corn production in Nebraska continue to call for record highs in both production and per acre yield.

Soybean production in Nebraska also remains on target to set records for total production and average per acre yield.

Final production results will be released in January 2019.

Groskurth said that the November report continues to show that soybean and corn harvest in the state continues to lag behind last year and the 5-year average. He did say he felt farmers were catching up on the harvest the past week.

Alfalfa hay production was up 10 percent from last year, and all other hay production was up 28 percent from the previous year, giving the state a lot of hay on hand. The hay stocks report will be released in December.

Pasture and range conditions continue to be very good.

Groskurth said the results of the 2017 Census of Agriculture will be released February 21, 2019. He also mentioned that this would be his last CARC meeting as he is retiring from USDA-NASS on January 5, 2019.

Groskurth's PowerPoint presentation will be posted on the CARC website.

Nebraska Emergency Management Update
Provided by Brian Tuma, Assistant Director

Tuma discussed the stress on resources that both the Federal Emergency Management Agency (FEMA) and the Nebraska Emergency Management Agency (NEMA) have been experiencing due to the horrific hurricane season in 2017 and additional disasters that have occurred in 2018.

He said that states have been called upon to help in national disasters, stretching both human and financial resources to the limit. He said he feels that going forth states are going to be called upon to bear more of the brunt of their own natural disasters, and that organizations such as the Emergency Management Assistance Compact will play a key role.

Other points that Tuma discussed included:

- Two weather disasters were experienced in Nebraska in 2018. One was the snowstorm that hit central Nebraska in April of this year. The other was a period of strong thunderstorms, tornadoes and straight winds that occurred in June and covered 11 counties in northeast Nebraska.
- There has been some lowland flooding along the Missouri River as a result of additional releases upstream by the Army Corps of Engineers. This is due to heavy snowfall runoff from last year and additional heavy rains during the spring and summer along the river. They are hoping levels will subside prior to this winter's runoff.
- The last serious wildfires in Nebraska occurred in 2006 and 2012. There are mounting concerns that parts of Nebraska could be vulnerable to major wildfire breakouts again due to the recent favorable conditions. Excessive pasture and range growth has created a lot of fuel if a fire were to start. There are also concerns about the continuing proliferation of red cedar trees that create a real fire danger.
- Due to recent vacancies at NEMA, the state's five-year strategic hazard mitigation plan had been delayed. Tuma said they now have a person working on the plan full time, and it should be completed prior to the May 2019 deadline.
- Tuma mentioned that the UNL Medical Center has received a $3 million grant to build a regional public health response network. He said this will have a major positive impact on being able to respond more quickly and efficiently to public health concerns.

Other Comments

State Climatologist Martha Shulski, talked about a group made up of several state and federal agencies, as well as other interested organizations and individuals who are seeking ways to combine climate information into one easy to interpret communication. Shulski said she developed an initial model that is designed to congregate the information into one graph and communication piece. Committee member Mark Svaboda, director, National Drought Mitigation Center, said the group plans to meet again to continue and improve on their efforts. He said that sometime in the future they may inquire to see if CARC is interested in aiding in disseminating the information.

CARC's ranch representative, Barb Cooksley, reported that her area of the Sandhills has had excessive rain this year. The average rain for Custer County is about 22 inches, and it has already recorded 27 inches of annual precipitation. Most of the rains this summer were not more than an inch and a half at a time so there was little runoff. She said the result has been a very good haying season. She also mentioned that there has been exceptional growth in the pastures and rangeland, meaning there is a heavy fuel load, and the potential for wildfires is growing.

Department of Natural Resources CARC representative Shuhai Zheng, mentioned his department has a contingency plan for possible flooding along the Missouri both at the northeast and southeast ends of the border. They are hoping that flooding will subside as flows are reduced, but the winter releases will continue to be higher than normal due to runoff from heavy rainfall this summer.

CARC's crops representative Carl Sousek, mentioned the challenges many Nebraska farmers faced this fall due to the constant stop and start again harvest season that was the result of significant rain and snowfall.

The meeting was adjourned 11:20 a.m.

CARC Meeting Minutes (DRAFT)
Monday, June 4, 2019
901 Hardin Hall, UNL East Campus

Meeting was called to order at 9:34 a.m.

In Attendance:
Committee members or representatives: Amelia Breinig (chair), Nebraska Department of Agriculture; Dr. Shuhai Zheng, Nebraska Department of Natural Resources; Matt Joeckel, UNL Conservation and Survey Division; Tyler Williams, UNL Extension; Carl Sousek, crops farmer; Bryan Tuma, Nebraska Emergency Management Agency; and State Senator Steve Halloran, chair, Nebraska Legislature Agriculture Committee.

Staff and Audience: Brian Fuchs, National Drought Mitigation Center; Martha Shulski, Nebraska State Climatologist; Steve Roth, Nebraska Department of Agriculture; Nick Streff, USDA-NASS (National Agricultural Statistics Service); Marcia Trompke, Central Nebraska Public Power and Irrigation District; David Pearson, National Weather Service-Omaha, Eric Zach, Nebraska Game and Parks Commission; Ginger Willson, Senator Ben Sasse's office; Donny Christensen, Nebraska Emergency Management Agency; Nicholas Walsh, Nebraska Emergency Management Agency; Michael Hayes, University of Nebraska; Pascal Ntagunda, University of Nebraska; Libert Niyonkuru, University of Nebraska; and Doug Klein, USDA-Farm Service Agency.

Committee Chair Amelia Breinig opened the meeting stating that CARC follows provisions in Nebraska's Open Meetings Act and a copy of the act was available for review. She also had copies available of the affidavits of the public notices published in the Lincoln Journal Star and Kearney Hub newspapers on May 17, 2019.

Minutes from the Nov. 19, 2018 CARC meeting were accepted by the committee as presented.

Reports were provided as follows:

Nebraska Drought Conditions and Water Supply Update
Presented by Brian Fuchs, National Drought Mitigation Center

Past/Current Climate & Drought Report
The U.S. Drought Monitor map from a year ago, showed only a small area of southeast Nebraska abnormally dry or D1 drought conditions with the rest of the state drought free.

For the United States as a whole last June, the map indicated exceptional and extreme drought conditions in a significant portion of the four-corner region (Colorado, Utah, Arizona and New Mexico) of the country. There were also areas of abnormally dry conditions, D1 and D2 drought conditions, in many areas of the western United States as well as in North Dakota, South Dakota, Kansas, Oklahoma and Texas.

In the next 6-months, significant rainfall across the country resulted in 3-4 class improvements in previously drought-stricken areas. The U.S. Drought Monitor map for last May, showed only a few small areas of the country with abnormally dry or D1 conditions.

Nebraska remains drought free as it has been for several months. Fuchs commented that it is quite unusual for Nebraska to have no drought or even abnormally dry conditions at this time of year, and knowing the state's history, wondered when a switch to dry conditions could come.

Temperatures in Nebraska in May ranged from 8-10°F below normal and were 2-4° below normal the past 60 days. Meanwhile, precipitation amounts during that time frame were well above normal resulting in a cold, wet spring.

Most of the High Plains region had well-above-normal precipitation in May with some areas receiving 400percent above normal rainfall for the month.

Cold and wet conditions have prevailed in Nebraska during the past two months. These conditions have slowed seed germination for row crops that have been planted this spring.

The current NLDAS Soil Moist Model indicates that all of Nebraska is showing very adequate to above surplus amounts of soil moisture up to three foot deep of the soil profile. Many fields in the state still have standing water.

The U.S. Seasonal Drought Outlook for the next three months indicates just a very few areas in the entire country expected to have persistent drought conditions. Fuchs commented that the United States has its lowest level of drought in the 20 years the U.S. Drought Mitigation Center has been issuing its Drought Monitor.

Here is a climate/drought summary provided by Fuchs during his PowerPoint presentation:

- Cooler than normal conditions have dominated the state and region so far in 2019 with Nebraska averaging about 3-5 ° F below normal.
- Almost the entire state of Nebraska has recorded above-normal precipitation for this year so far with areas of north central Nebraska 3-6 inches above normal.
- During the spring (March-May), the entire region has been below normal for temperatures with the northern portions of the Plains 6-8° F below normal and the southern portions 2-4° F below normal.
- Nebraska is drought-free and has been since early September 2018. There has been no abnormal dryness depicted since May. The last time Nebraska had 10 percent or more of the state in drought was August 2017.
- The seasonal drought outlooks do not show drought conditions developing in Nebraska through the end of August 2019.

<u>Nebraska Water Supply Update</u>

Snowpack in the western United States, especially in the Rocky Mountains, has been way above normal. Water equivalency levels in those areas are 200 to 400 percent above normal. That would indicate significant runoff into the Platte River basin in Nebraska later this summer. Fuchs did point out however, that the runoff may come later or even slower than normal due to below normal temperatures in the higher elevations. A prolonged runoff season, coupled with additional rainfall in the basin may result in additional flooding across Nebraska.

Water supplies in streams, lakes and reservoirs along the Platte and Republican Rivers are near, at, or above water storage capacities.

Lake McConaughy is currently at 88 percent full pool compared to 85.4 percent a year ago. Inflows into the lake have been running 2,940 cubic feet per second, which is almost double the amount at the same time last year. Inflows along the Platte at Overton and Grand Island have been nearly double the amount in June of last year.

Fuchs said one positive result of the higher river levels and faster flow, is that it "scours" the riverbed of weeds and debris.

The Central Nebraska Public Power and Irrigation District (CNPPID) reports that the canal system along the Platte is at near capacity in preparation for irrigation season.

The 14-day average stream flows in Nebraska have been running far above average and in some cases near, at, or above record amounts.

Most of the water supply reservoirs along the Republican River basin are far above conservation pool levels compared to levels in November of last year. Storage level at the Harlan County Reservoir is at 100 percent, significantly above levels last June.

Fuchs commented that Irrigation season could start later than normal in Nebraska, which can be good for producers in regards to irrigation costs. However, there have been challenges in planting row crops due to the wet conditions.

Marcia Trompke with CNPPID, commented at the meeting, that irrigation season in her district typically would begin Monday (June10) but with all the rain they aren't anticipating the season to get into full swing for another month. This is raising concerns about having to move more water downstream that could possibly contribute to possible flooding along the Platte.

Here is a water supply summary provided by Fuchs during his PowerPoint presentation:

- A significant amount of water is stored and still accumulating in the Rocky Mountains, which will come through the Platte Basin yet this year.
- Lake McConaughy is currently 88 percent of capacity, which is slightly higher compared, to levels in November 2018 (last CARC meeting).
- The Republican River basin reservoirs are higher than in November as water levels increased due to the lack of irrigation and recharge taking place.
- Harlan County Reservoir is holding about 164,722 acre-feet more water now than in November 2018.
- Harlan County Reservoir is holding about 130,638 acre-feet more water now than at this time last year and is about 128,350 acre-feet above average for this time of year.
- All reservoir levels and storage should hold steady until or even increase until the irrigation season begins.

Fuchs PowerPoint presentation will be posted on the CARC website.

Nebraska Climate Update

Presented by Martha Shulski, Nebraska State Climatologist

This past fall saw temperatures below normal in Nebraska, especially in the eastern portion of the state. The Panhandle had the driest conditions during that period but those conditions have since been mitigated.

During the winter months, snowfall was plentiful throughout the state with record amounts recorded in Lincoln and Omaha. Temperatures were also below normal with Nebraska having its eighth coldest February on record.

With such cold weather conditions, Shulski said it was important for UNL Extension to have a tool to identify potential for cattle stress. Such a tool exists that tracks wind chills over a period of time. Wind chills need to be 30° F below zero in order to qualify for USDA's Livestock Indemnity Program (LIP). Information from the Winter Cattle Stress tool was sent to USDA to supplement the LIP criteria.

In looking at historic weather trends for the month of February in Nebraska, Shulski said that the long-term trend (over 100 years) has indicated warming temperatures with little change in precipitation amounts. However, the short-term trend (the past 30 years) for the month of February indicates temperatures have been cooling in the state with wetter conditions.

It was conditions this past February that set the stage for the major floods that occurred in Nebraska in March. This included saturated and frozen soils, deeply frozen rivers and streams, and accumulated snow with high water equivalency.

Winter storm Ulmer came to Nebraska on March 12-13. A blizzard with sustained 25-mile an hour winds in the western part of the state, coupled with heavy rain in the east, led to one of the most impactful floods ever recorded in the state. Many rivers stayed above flood stage for weeks. The damage in Nebraska has been estimated at more than $2 billion. The floods are blamed for four deaths, numerous cattle losses, transportation in and out of some communities being temporally halted, water quality concerns and grain losses.

Shulski commented that the National Weather Service did a good job of predicting events prior to the storm and warning people what was to come. She added that there has been some concerns that the response during and after the storm events could have been better.

The Nebraska Emergency Management Agency and Federal Emergency Management Agency held a stakeholder meeting on April 24 to discuss ways to improve communication and mitigation during such weather events in the future.

The spring months in Nebraska included a cool March, warm April and a very wet (tied with 1995 for record wettest) and cool May.

Rain occurred in various places throughout the state in half to three quarters of the days in May. Some places received more than half of their annual total of rainfall in that 31-day period. The abundant rainfall led to continued flooding in some areas and delayed planting of row crops in most places.

In looking ahead to the rest of June, the National Climate Prediction Center was calling for greater chances of below normal temperatures and above normal precipitation for most of the state. The 3-month outlook (June-July-August) calls for much of the same wet and cooler trends.

Shulski also showed a new Grassland Production product from the National Drought Mitigation Center and National Weather service that is designed to estimate the potential for grassland production based on climate information in the western grassland ranges of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma and Texas.

Potential weather impacts this summer due to current conditions include: slow development of the corn crop because of planting delays, yellowing corn due to saturated soils, nitrogen loss and weed control issues.

A cool wet June as currently being predicted could result in poor crop development in Nebraska. This could create problems such as shallow root systems or the need for a warm September with no early frost.

Shulski's PowerPoint Presentation will be posted on the CARC website.

Nebraska Hay Stocks and Crop Condition Report
Presented by Nick Streff, USDA NASS

In March, Nebraska producers had intentions to plant 9.7 million acres of corn, up 100,000 acres from the previous years. Planting intentions for soybeans were at 5.4 million acres, down 300,000 acres from the previous year. Streff pointed out these were intended planted acres and the actual number of planted acres could change in the coming months due to planting delays, government programs and/or price fluctuations.

The first USDA-NASS prediction of the winter wheat harvest in Nebraska in 2019 would result in the second lowest number of harvested acres in the state. The estimate of 50 bushels per acre average would be up one bushel per acre from last year. The record in Nebraska is 54 bushels per acre. The majority of Nebraska's winter wheat crop is rated in good or excellent condition but is running well behind average for being headed.

As expected, topsoil and subsoil moisture throughout most of the state is rated as adequate or in surplus due to ample rainfall this winter and spring.

USDA-NASS puts out a hay stocks survey twice a year, with the first one released in May. As of May 1, hay stocks in Nebraska were estimated at 1.07 million tons, up 370,000 tons from the previous year. The 10-year average is 1.1 million tons. The lowest recorded stocks in the last 10 years was 610,000 tons in 2013.

The following Crops Progress and Conditions report for Nebraska was released by USDA-NASS on June 2:

- Corn condition rated 1 percent very poor, 2 percent poor, 23 percent fair, 67 percent good, and 7 percent excellent. Corn planted was 88 percent, behind 99 percent last year and 98 percent for the five-year average. Emerged was 67 percent, well behind 90 percent last year and 88 percent average.
- Soybeans planted was 64 percent, well behind 94 percent last year and 87 percent average. Emerged was 39 percent, well behind 74 percent last year and 60 percent average.
- Winter wheat condition rated 2 percent very poor, 6 percent poor, 25 percent fair, 48 percent good, and 19 percent excellent. Winter wheat headed was 45 percent, well behind 67 percent last year and 75 percent average.
- Sorghum planted was 36 percent, well behind 77 percent last year and 70 percent average.
- Oats condition rated 1 percent very poor, 3 percent poor, 35 percent fair, 56 percent good, and 5 percent excellent. Oats planted was 96 percent, near 100 percent both last year and average. Emerged was 88 percent, behind 96 percent last year and 98 percent average. Headed was 14 percent, well behind 36 percent last year, and behind 33 percent average
- Pasture and range conditions rated 1 percent very poor, 1 percent poor, 15 percent fair, 70 percent good, and 13 percent excellent.

Streff's PowerPoint presentation will be posted on the CARC website.

Water Availability and Outlook Committee (WOAC) Discussion
Requested by Brian Fuchs, National Mitigation Center and David Pearson, National Weather Service Omaha

Fuchs said that representatives from several state and federal weather-related agencies have been meeting on a regular basis to share information and coordinate communication efforts. Many of the agencies are either represented on CARC or have been members of the Water Availability and Outlook Committee (WOAC) which was originally created in the State Drought Plan.

Pearson, who has been leading the organization of the group and said the goal has been to have a consolidated effort among the various agencies in procedures and information dissemination. Some of the agencies and organizations that have been represented at the meetings are: High Plains Regional Climate Center, National Drought Mitigation Center, several Nebraska offices of the National Weather Service, State Climatologist Office and UNL Extension.

Fuchs and Pearson stated that at their last meeting, the question came up as to whether or not it makes sense to re-activate the WOAC, which has been dormant the past few years.

Breinig pointed out that the structure and objectives of WOAC are spelled out in the most recent update of the State Drought Plan that was accepted by CARC in 2000. She suggested that parties interested in activating WOAC meet to clarify the objectives, procedures and structure of the committee. Interested parties plan to meet in the near future and report back at the next CARC meeting.

Other Updates from CARC Members/Advisors

Breinig read the following weather conditions report submitted by CARC livestock representative Barb Cooksley of Anselmo who was unable to attend the meeting:

Winter was bitter cold, snowy, windy. Our ranch doesn't start calving until late April, so we missed the blizzards and the flooding.

The last late blizzard was 20 miles west, the flooding started five miles east. We feel so blessed.

The rains have continued and even the Sandhills are "full." Hard to tell a difference between ground and surface water! We are close to 12 inches of moisture for the year, with over six inches coming in May. Our average rainfall is around 19-22" inches.

Sincerely,
Barb Cooksley

In recapping conditions in his area (Prague), Carl Sousek, crops representative for CARC, mentioned that winter set in early and therefore a lot of cover crops were never planted. He said the heavy rains and flooding caused a lot of damage to conservation structures in the area. He commented that farmers and ranchers in Nebraska have had to face one challenge after another including weather conditions, large surpluses of grain, high taxes, tariffs and devalued land due to flooding. Concern is mounting with financial institutions receiving requests for operating costs. Farmers have to make tough planting decisions the longer planting is delayed.

The meeting adjourned at 11:05 a.m.

Climate Assessment and Response Committee
Meeting Agenda
Wednesday, Nov.13, 9:30 a.m.
901 Hardin Hall, UNL East Campus

Call to Order: Chair, Nebraska Department of Agriculture: Amelia Breinig, Asst. Director

Review of Minutes from June 4, 2019

Nebraska Drought Conditions/Water Supply Overview: Brian Fuchs, National Drought Mitigation Center

Climate Update: Martha Shulski, State Climatologist

Crop Progress and Conditions Report: Nick Streff, USDA-NASS:

Other Updates from CARC Members/Advisors

Adjournment

May 21, 2015

MEMO TO: Gov. Pete Ricketts

FROM: Bobbie Kriz-Wickham, Assistant Director, CARC chair

SUBJECT: Climate Assessment Response Committee report

The Nebraska Climate Assessment Response Committee (CARC), which I chair on your behalf, met on Wednesday, May 20, 2015. By statute, CARC must meet at least twice each year; the group generally holds a spring and a fall meeting to discuss present and predicted weather conditions.

Past and Present

The U.S. Drought Monitor (the most current map can be found below) shows Nebraska with 7 percent of the state in a Class I drought (tan color) and about 37 percent abnormally dry (yellow color). This is a marked improvement from the beginning of April, reflecting our recent wetter and cooler weather pattern, but it is important to note the impacted area (a narrow corridor that stretches from the southwest to the northeast) has been in an ongoing pattern of dryness and warmer temperatures since the beginning of the year. This same area is at 50 to 90 percent of normal precipitation for the period dating back to October 2014.

Nationally, California remains in its historic drought, but conditions over the past year have improved for the desert Southwest, Texas, Oklahoma and Kansas. The Upper Midwest has had an intensifying drought pattern.

The spring and summer streamflow forecast for May 1 shows below-normal streamflow predictions for the areas in Colorado, Wyoming and the northern Rockies that feed the North Platte and Missouri rivers, while the area that feeds the South Platte river was closer to normal but has seen recent heavy rains and new snowpack that has forced flood mitigation actions.

Regarding the water supply conditions for the state, Lake McConaughy is at about 78 percent of capacity, with inflows that are presently above normal. It is 8.6 feet above where it was last June. The water supply in the Republican River basin reflects on the ongoing dryness, with Harlan County Dam at 60 percent full, and other basin reservoirs anywhere from 20 percent to 100 percent, but officials said the area is still in better condition than a year ago.

Outlook

Warm sea surface temperatures in the equatorial Pacific Ocean, contributing to an El Nino weather pattern, and additional access to Gulf of Mexico moisture are both influencing our weather conditions. Officials say there is a 90 percent chance this pattern will continue through the summer, with an 80 percent chance of it continuing into the fall and winter.

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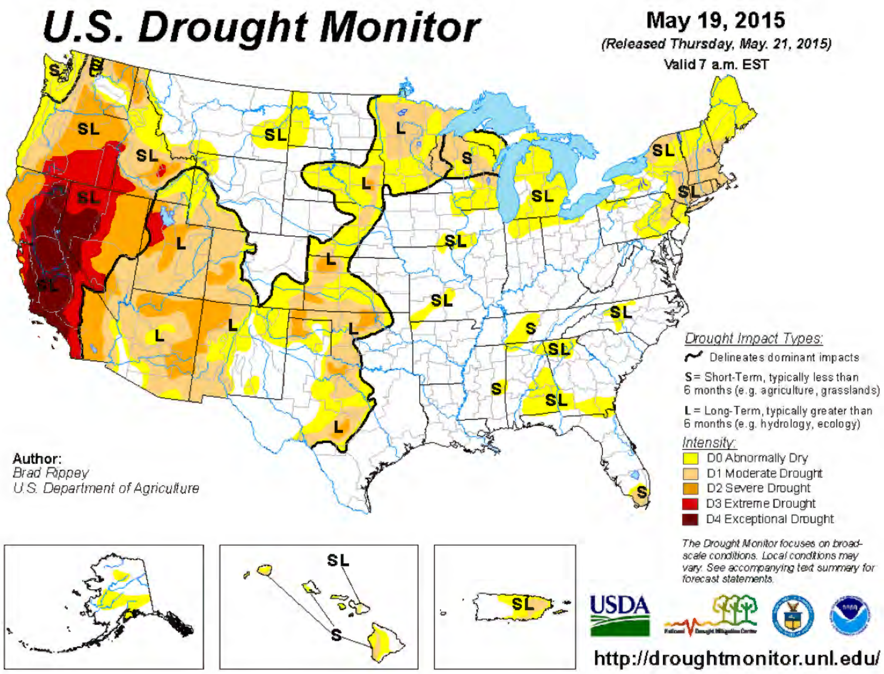
Other

The National Agriculture Statistics Service reports that Hay Stocks for Nebraska, as of May 1, are up 9 percent from a year ago, reflecting a good growing season in 2014. Winter wheat yields are expected to be down from a year ago, reflecting some winter kill. The recent snowfall in the Panhandle will also likely have a further negative impact on yields, although the full extent of impact will remain unknown until harvest, according to the Nebraska Wheat Board. Corn planting across the state is at about 85 percent complete, just shy of average, while soybean planting, at 41 percent complete, is 10 percent behind average.

The Nebraska Farm Service Agency reported that the recent flooding in eastern and southeast Nebraska will force some replant situations. However, the crop damage has not been extensive enough to trigger requests for federal secretarial disaster designation through the United States Department of Agriculture (USDA). Such designation requires a county to have at least a 30 percent loss of at least one crop to qualify.

The committee did not set a next meeting date, but agreed to monitor conditions and meet as warranted.

Please let me know if you have any questions.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May 19, 2015
(Released Thursday, May. 21, 2015)
Valid 7 a.m. EST
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Delineates dominant impacts
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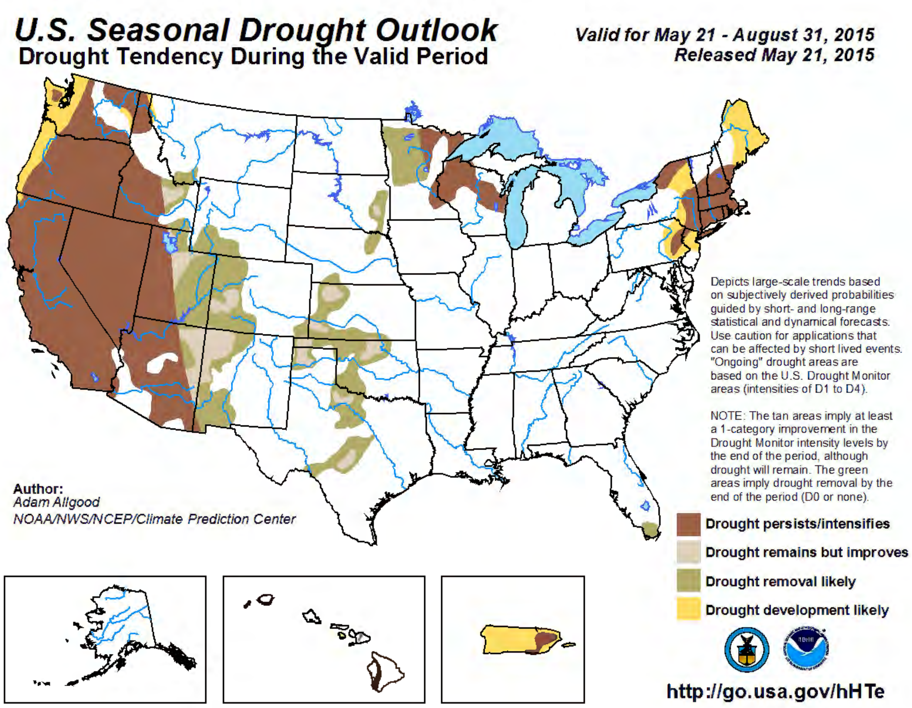
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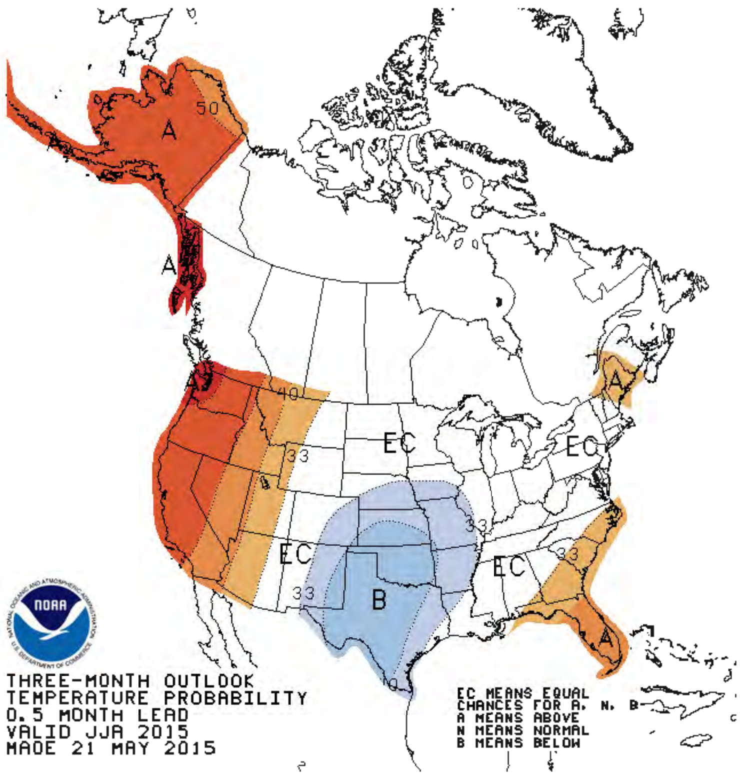

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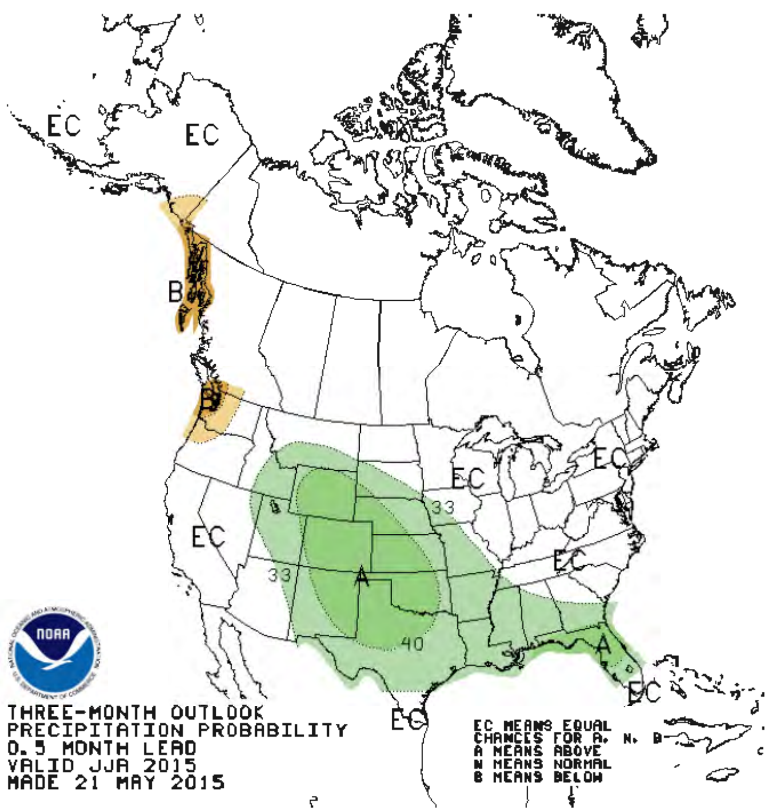

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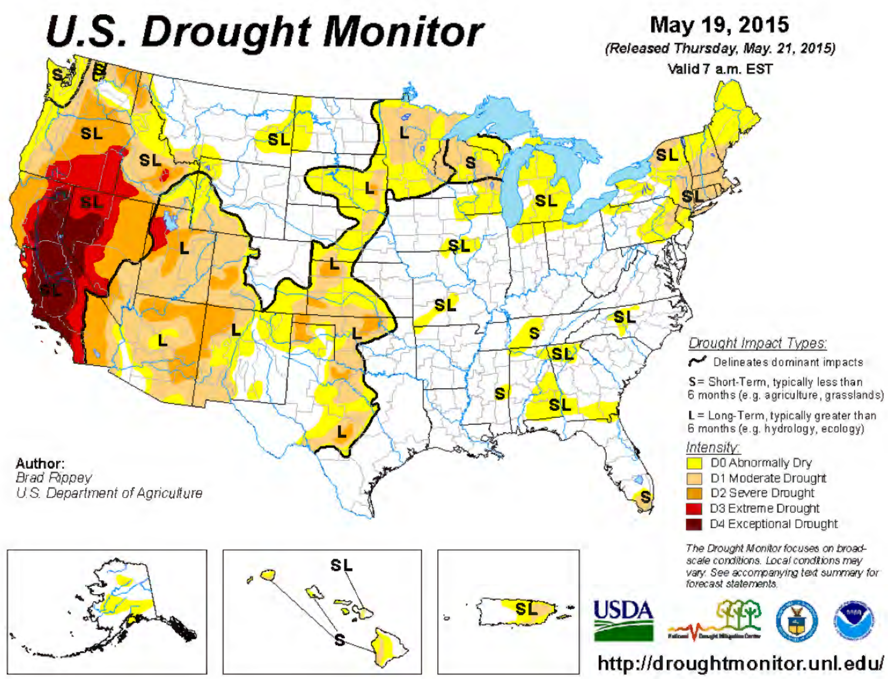
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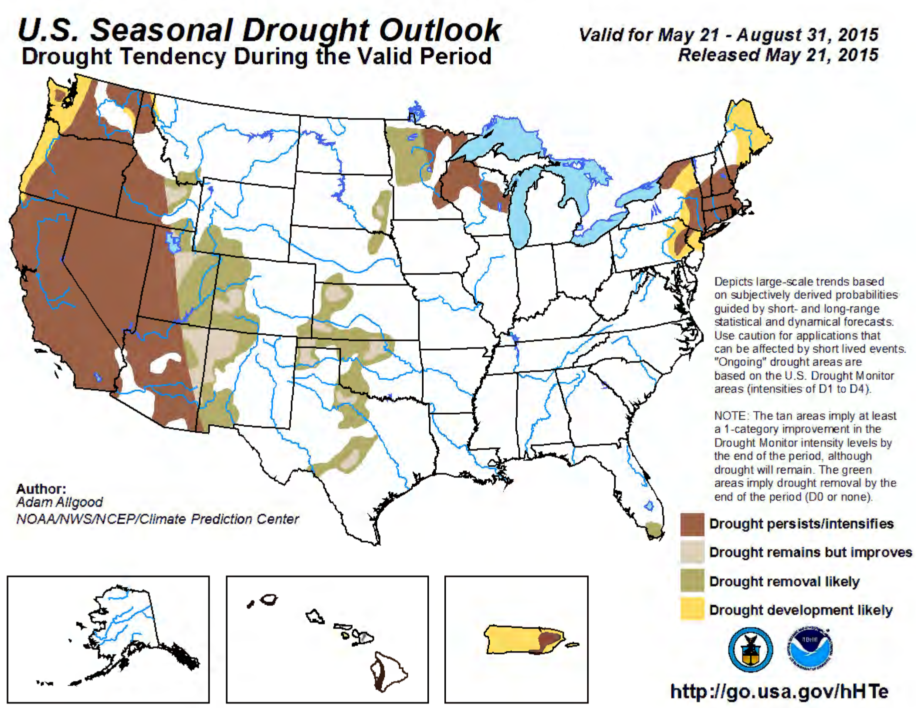
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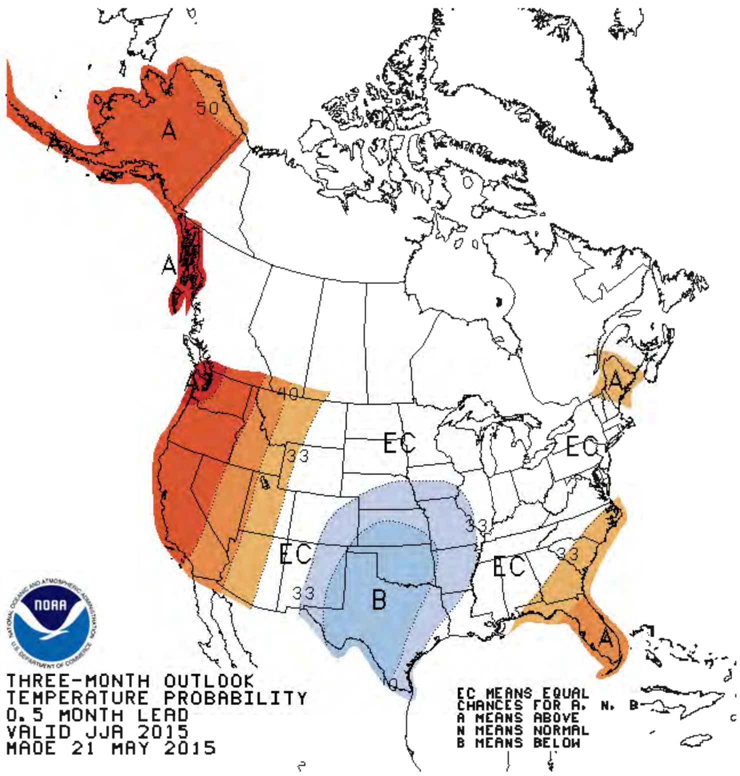
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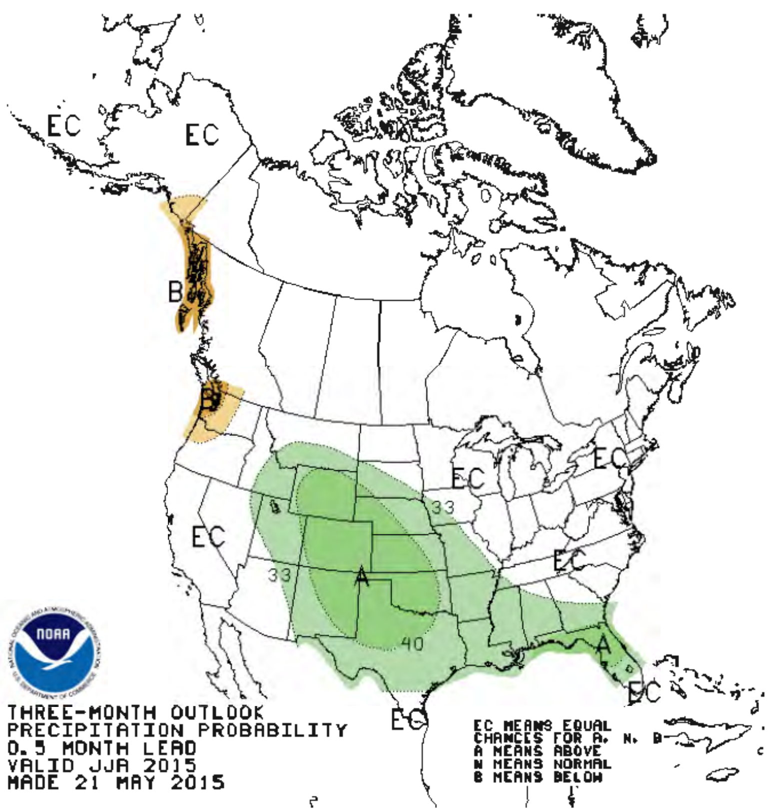
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The Office of Cyber and Infrastructure Analysis

National Protection and Programs Directorate
Department of Homeland Security

OCIA Climate Change Initiatives Overview

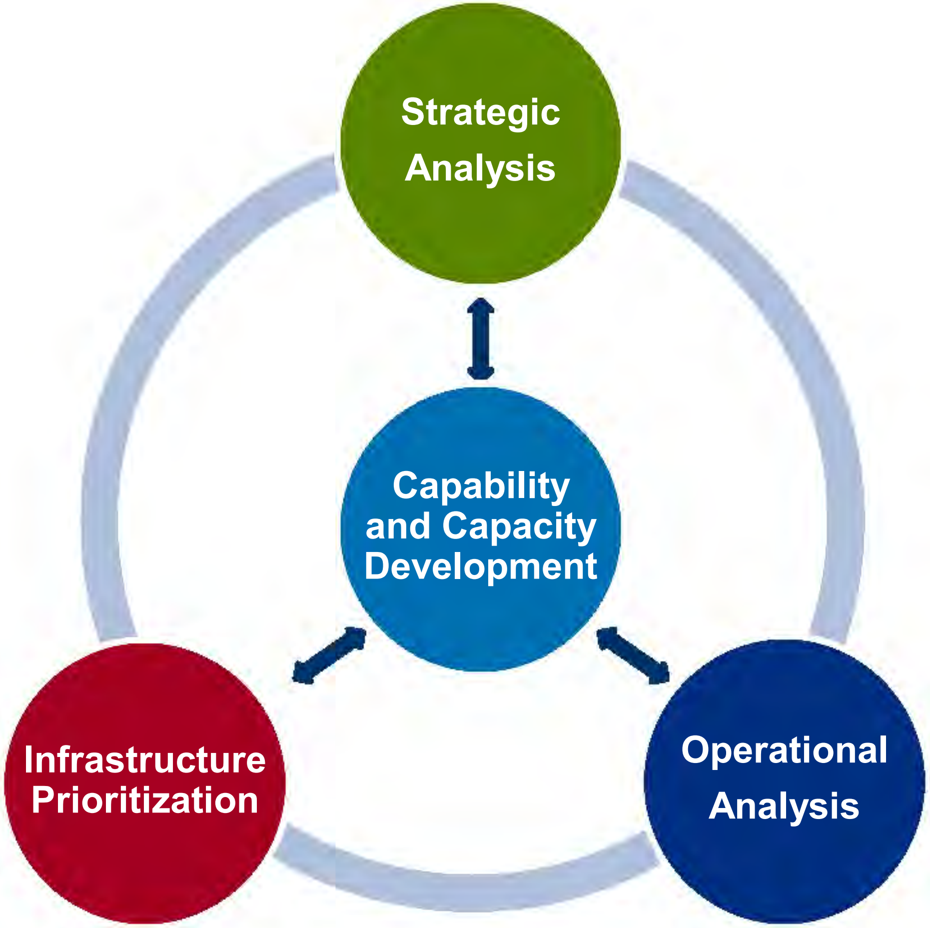
Nebraska State Agency Directors and Staff

September 19, 2014

Homeland Security

OCIA Overview

- Critical infrastructure consequence analysis and prioritization
- Critical infrastructure expertise, modeling and simulation capability, and interagency partnerships developed over the past 7 years
- Includes operational and strategic analysis of incidents and emerging risks
- Supports interagency, intergovernmental, international, and private sector partners with risk and consequence analysis



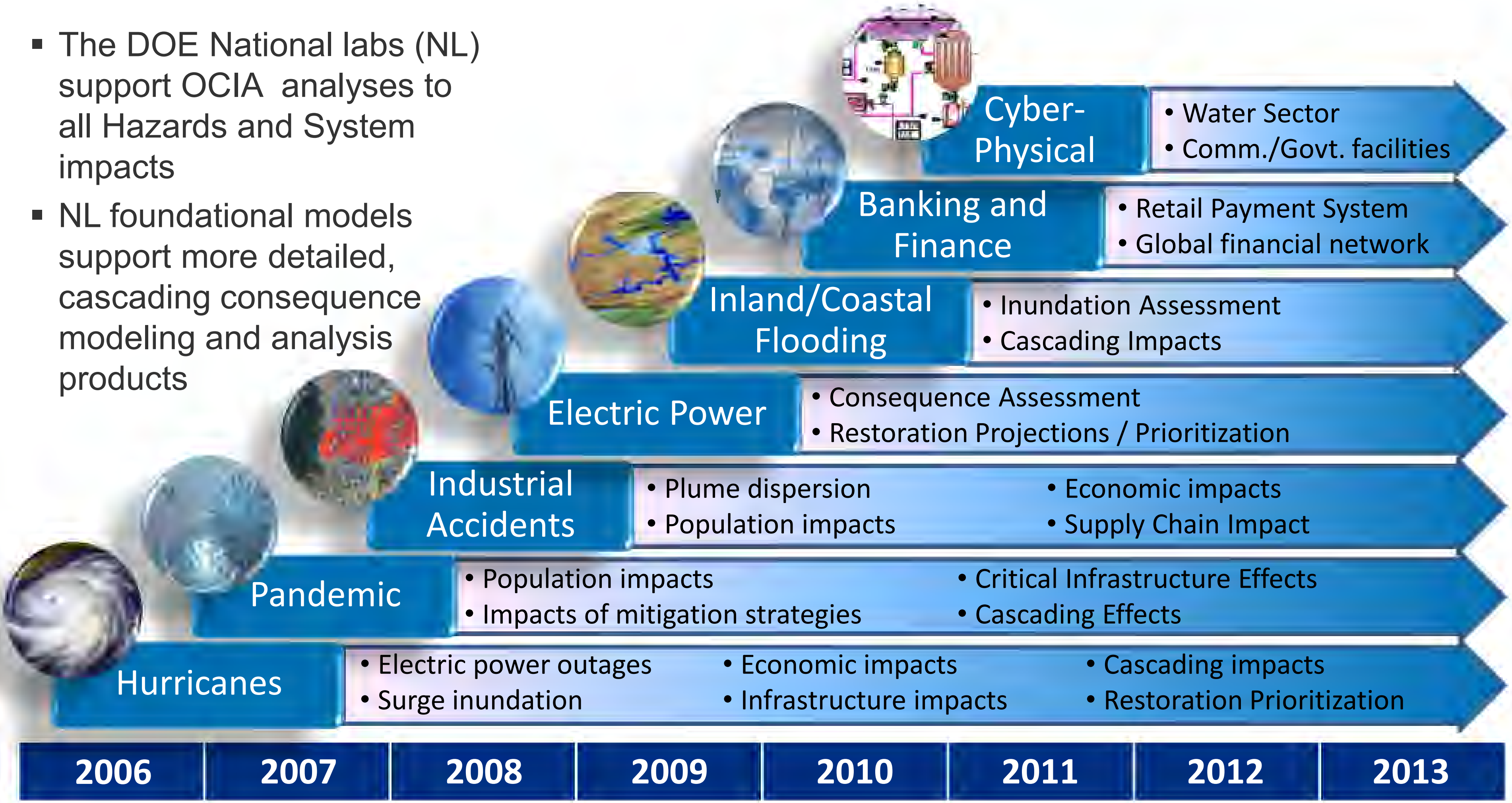
Homeland Security

OCIA Strategic Goals

- Provide timely and integrated risk modeling and analysis to DHS and National Infrastructure Protection Plan (NIPP) partners.
- Integrate infrastructure-related analysis and risk information into products and services in collaboration with and in support of partners and stakeholders.
- Provide critical infrastructure modeling and risk analysis that inform strategic prioritization of critical infrastructure resources and support exercises, training, and real-world incidents
- Establish an integrated approach for critical infrastructure risk analysis

OCIA Analytic Program Development

- The DOE National labs (NL) support OCIA analyses to all Hazards and System impacts
- NL foundational models support more detailed, cascading consequence modeling and analysis products



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OCIA Analyses

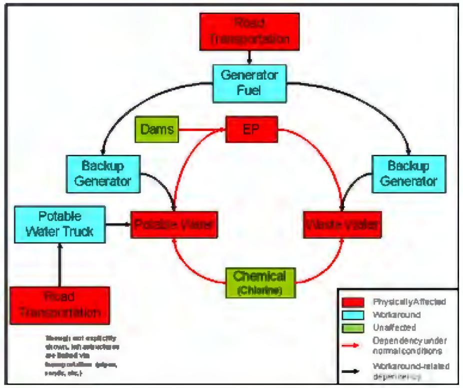
- Incident response/ad hoc request: quick-turn, focused analysis of infrastructure issues
  - Hurricane Sandy
  - Napa Earthquake
  - Bakken crude movement by rail
- Scenario analysis: impacts to infrastructure, population, and economy from hypothetical events
  - Hurricane swath studies
  - Pandemic modeling
  - Earthquake studies
- Strategic analysis: integrated analysis of emerging issues
  - National Risk Estimates
  - National Risk Profiles

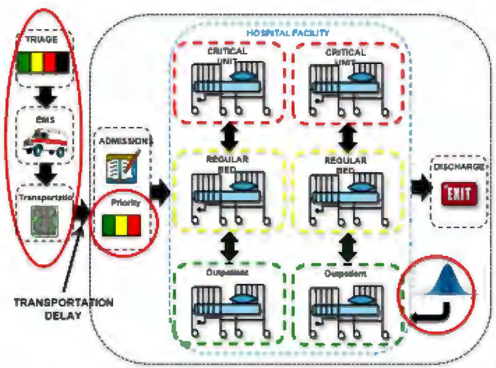
Homeland Security

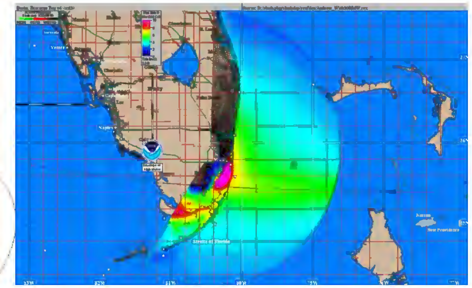
National Infrastructure Simulation and Analysis Center

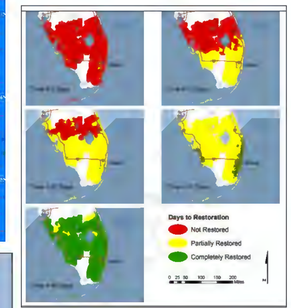
- USA PATRIOT Act (PATRIOT Act; Public Law 107-56; October 26, 2001) formally chartered NISAC stating that "[t]here shall be established the National Infrastructure Simulation and Analysis Center to serve as a source of national competence to address critical infrastructure protection and continuity through support of activities related to counterterrorism, threat assessment and risk mitigation."
- NISAC is collaboration between Los Alamos National Laboratory and Sandia National Laboratories and integrates the two laboratories' existing expertise in modeling and simulation to address the consequences of a disruption to critical infrastructure.

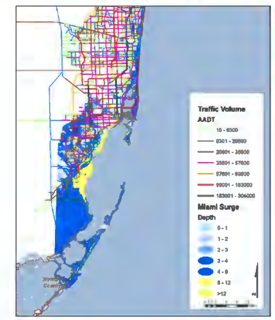
NISAC Analyses

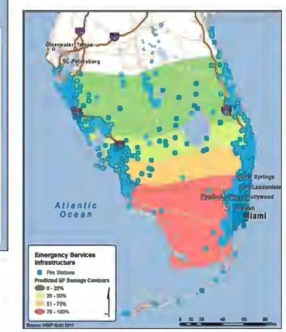


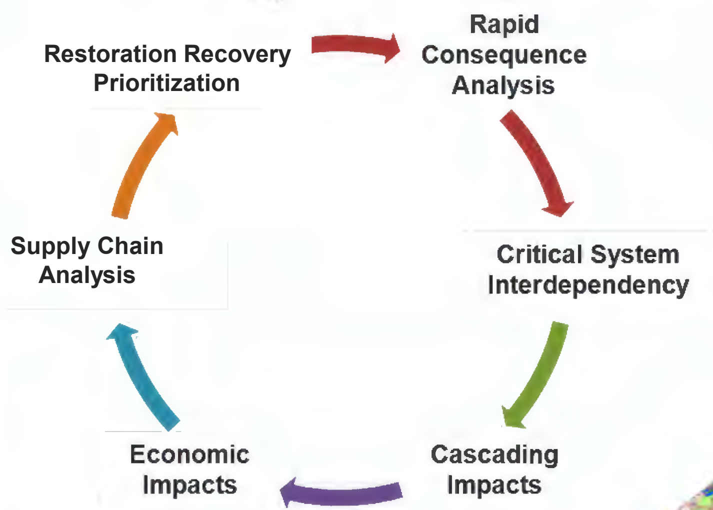


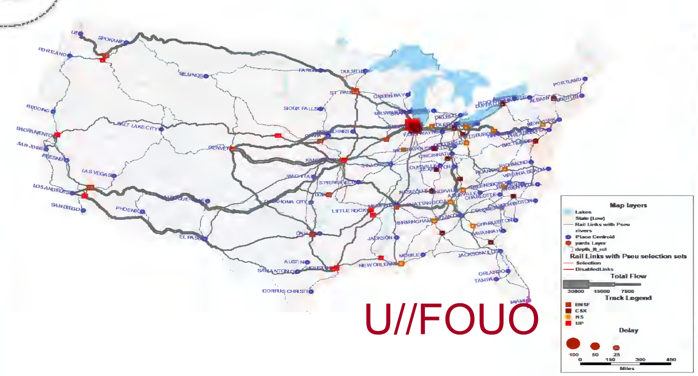


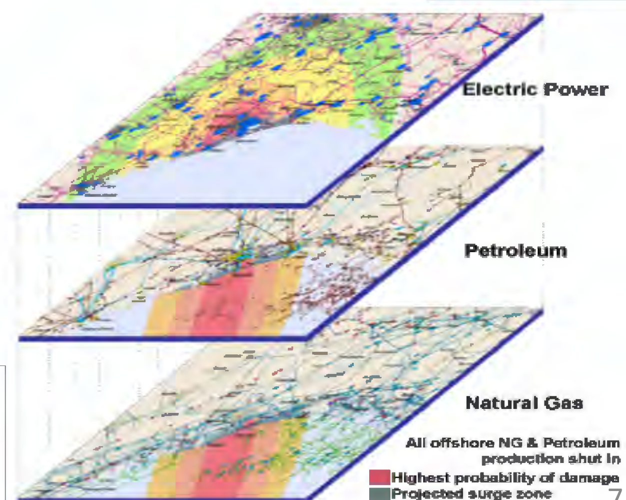










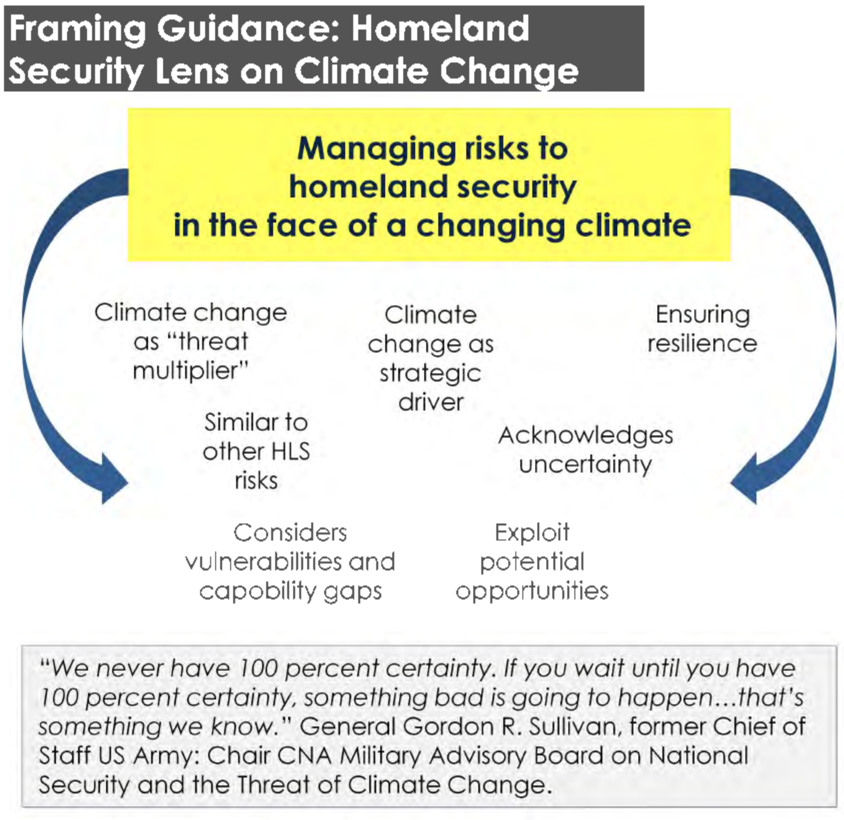


Homeland Security

DHS Climate Change Adaptation Roadmap

“Understanding how climate change may change our strategic landscape is at the heart of effectively managing risks to the Nation’s security. The DHS Climate Change Adaptation Task Force notes that the projected impacts of climate change pose direct and indirect security and resiliency risks to core homeland security missions and DHS infrastructure and operations.”

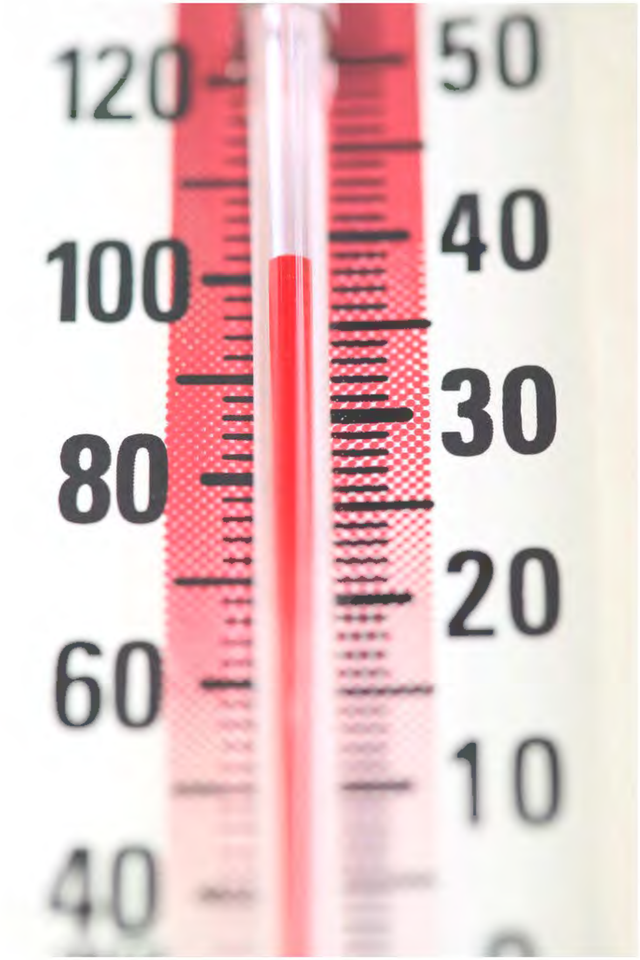
- DHS Policy for Climate Change Adaptation, 2011



Homeland Security

OCIA Climate Change Projects (FY2013)

- Initial Assessment of Climate Change Impacts on U.S. Critical Infrastructure: Increasing Temperature
- Regional Water Supplies in the Platte River Basin
- Capability Development for Water Supply Risk Analysis
- Legal and Policy Environment for Water Resource Management of the Ogallala Aquifer



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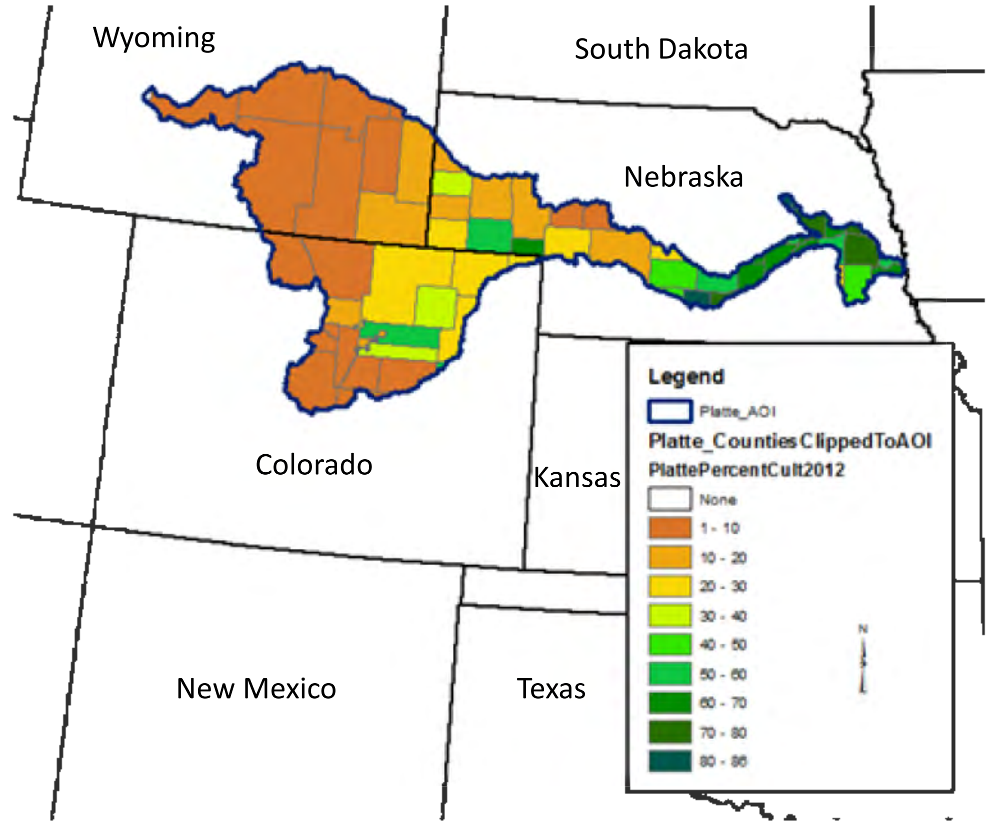
NISAC Platte River Basin Climate Change

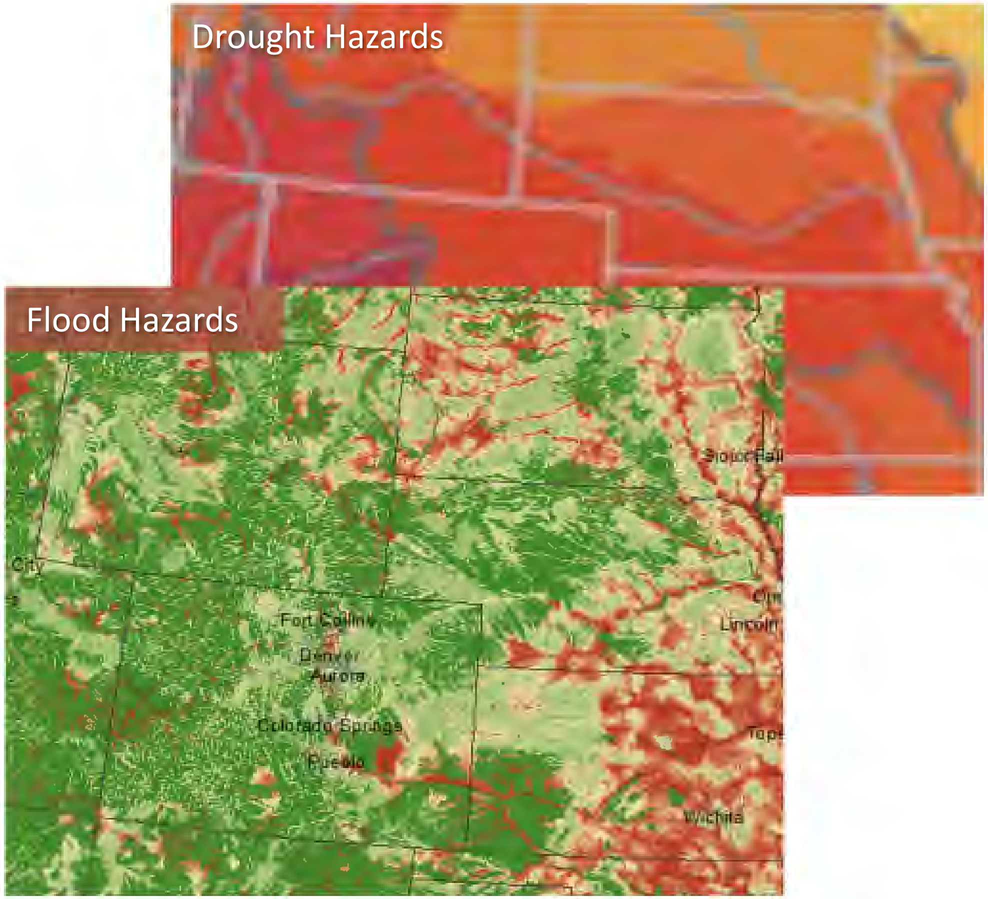
- Step 1 – Conduct literature search to identify existing data, climate projections and analysis tools to evaluate the projected impacts of climate on water availability and the potential effects of climate on infrastructures, environment and population in the Platte river basin.



Concentration of Agriculture in the Platte River Basin

Homeland Security

NISAC Platte River Basin Climate Change



- Step 2 - Use the existing information to provide a qualitative analysis of the potential basin-wide impacts across multiple sectors from
  - changes in flooding
  - extended drought
  - water quality changes
- Step 3 - identify examples of potential risk mitigation strategies and their implications.

Homeland Security

NISAC Platte River Basin Climate Change

- Over the next 50 years in the Platte River basin, projected climate change will increase variability in precipitation and increase average temperatures.
- The projected climate change puts six populated areas in the basin at greater risk for flooding: northwest Denver, Colorado, metropolitan area; Commerce City, Colorado; Central City, Nebraska; North Platte, Nebraska; Lexington, Nebraska; and Fremont, Nebraska.
- Multiyear drought can cause surface-water supply shortages across the basin and further depletion of water stored in the High Plains aquifer.
- Agriculture, the largest water user, holds priority in water rights. This is the fundamental issue to be addressed in order to offset water shortage risks to the other economic sectors.

NISAC Platte River Basin Climate Change

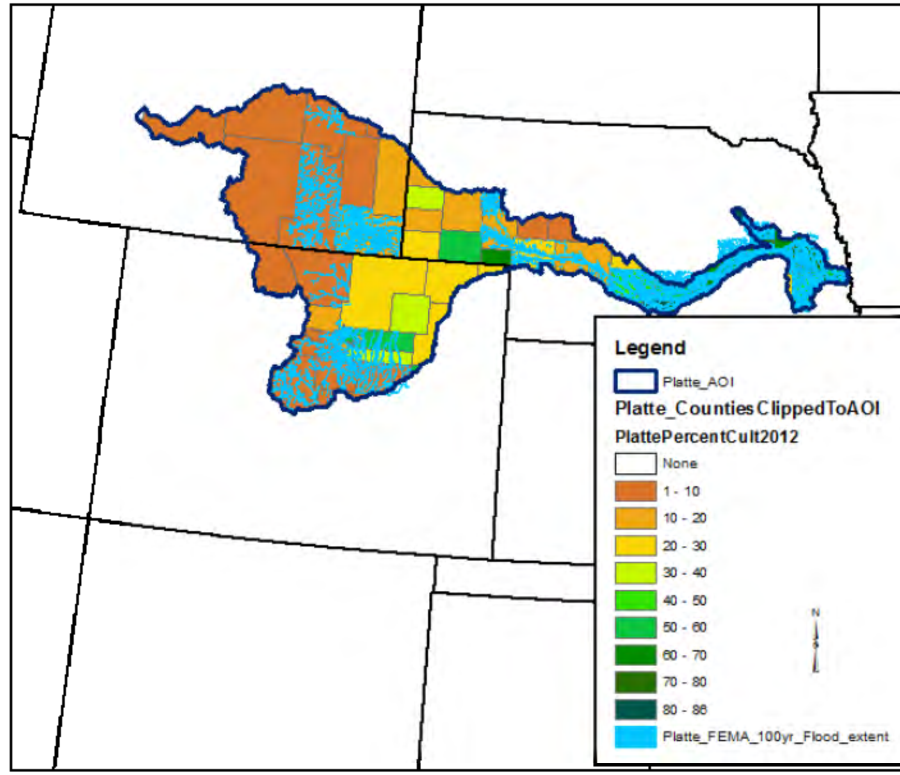
- Use-it-or-lose-it rules incentivize water use simply to maintain ownership of valuable water rights. Alternative systems, such as a bank for water rights through which rights could be leased, might provide a financial incentive sufficient to create more dynamic, adaptive water use.
- Additional analysis is also required to evaluate the risk that this mitigation incentivizes unreliable food and grain production, which would drive global food prices higher and create instabilities at the global scale.
- Long-term severe-to-profound drought will be difficult to mitigate because it requires changes to how water is allocated in a system with a long historical precedent for water rights allocation. Water shortages and re-allocation of water have the potential for far-reaching, unintended consequences.

Platte River Basin Scenario Analysis

- Increased variability in precipitation can cause three types of issues for water supply: too much water, too little water, and changes in water quality (due to flooding, drought, and/or changes in water use).
- For this study the potential impacts of increased climate variability in the next 30 years are evaluated using two general scenarios.
  - Increased flooding: 500-year flood becomes the 100-year flood
  - Increased drought: multi-year droughts become more common
- The drought of 2012 and extreme flooding event in 2013 in Boulder, Colorado, illustrate how greater variability in precipitation could cause year-to-year or multi-year changes, from severe drought to extreme flooding and back again.

Platte River Increased Flooding Impacts

- FEMA's floodplain mapping in the region is incomplete
- In the areas where the mapping is complete, the 500-year floodplain is very similar to the 100-year floodplain; however, there are some significant differences in a few urban areas within the region.
  - Large areas of residential, commercial, and industrial land are within the 500-year floodplain in northwest Denver.
- Steep topography in the western portion of the basin limits flooding
- Floodplain spreads out as the topography changes and again when the North and South Platte Rivers merge in Nebraska.
  - Topography also influences the speed of flow and therefore the force of floodwaters and the damage they cause to infrastructure and other sector assets.



FEMA 100-year Flood Plain with respect to percent cultivation for the Platte River Basin

Homeland Security

Platte River Increased Flooding Impacts (cont.)

Summary statistics for infrastructure assets in the 100-year floodplain and additional assets in the 500-year floodplain

Asset Type	Assets in 100-yr Floodplain	Additional Assets in 500-yr Floodplain
Chemical Plants	3	9
Electric Power Plants	15	3
Electric Power Substations	49	20
Petroleum Refineries	0	2
Petroleum Terminals	0	3
Public Health - Hospitals	1	3
Public Health - Nursing Homes/Assisted Living Facilities	8	36
Telcom - Wire Centers	18	7

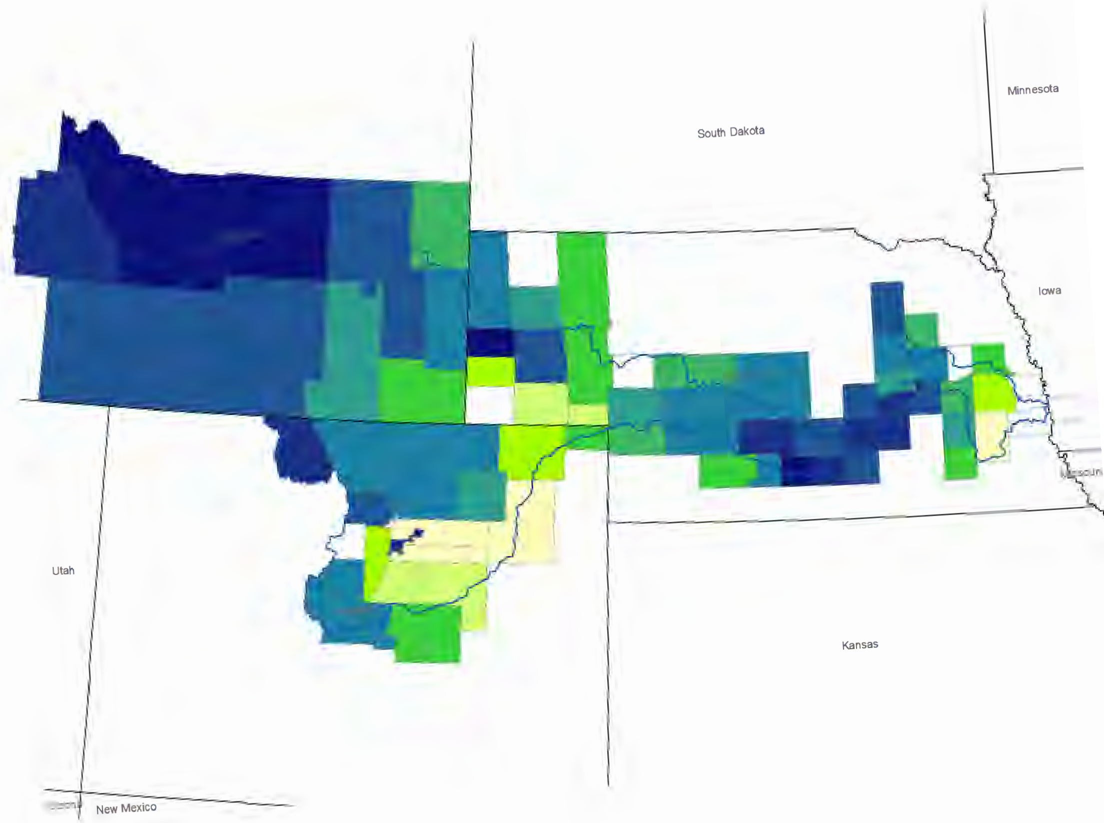
Homeland Security

Platte River Flooding Mitigation Options

- Standard flood risk reduction measures include building standards that prevent development in certain flood plains (e.g., the 100 year flood plain) and installing flood control features to limit the extent of those flood plains.
- To prevent disruption of lifeline services and reduce economic impacts, states and public utility boards could require infrastructure owner/operators to move assets out of the 500-year floodplain or install enhanced flood protection features sufficient to protect against the 500-year flood for isolated at-risk assets.
- State or Federal agencies could reduce asset risks due to flooding by constructing and maintaining enhanced flood protection measures for populated areas like the northwest Denver metropolitan area, Commerce City, Central City, North Platte, Lexington, and Freemont.

Platte River Basin Drought Impacts

- Dryland farms (unirrigated) are the first infrastructure operations that will be impacted by drought.
- Irrigated agricultural businesses are not as prepared for water-supply disruptions.
- Water restrictions for urban areas are the next phase of drought impacts



Percent of harvested land that is irrigated

Homeland Security

Platte River Drought Mitigation Options

- Long-term severe-to-profound drought will be difficult to mitigate because it requires changes to how water is allocated in a system with a long historical precedent for water rights allocation.
- Water shortages and re-allocation of water have the potential for far-reaching, unintended consequences.
- Alternative systems, such as a bank for leasing water rights, might provide financial incentives sufficient to create more dynamic, adaptive water use.
  - Additional analysis would be required to determine whether this option would create a regional economy that is more resilient to drought and more likely to support economic growth.
  - Additional analysis is also required to evaluate the risk that this mitigation incentivizes unreliable food and grain production, which would drive global food prices higher and create instabilities at the global scale.

Climate Change and Energy Infrastructure

Long Term Goal	• Delineate issues and mitigation strategies for risks to energy infrastructure associated with climate change
FY2014 Goal	• Identify critical climate-related vulnerabilities and leverage points for increasing the resilience of the electricity system in the Eastern Interconnection, with an initial focus on electricity supply and demand.
Project Partners	• Pacific Northwest National Laboratories • EPA, DOE, IP/SOPD • FEMA Regional Planners; Private sector owner/operators
Key Aspects	• Builds on DOE-funded work on how different climate and climate policy scenarios affect the evolution, cost, and reliability of the US electricity system in the Eastern Interconnection in terms of regional technology mix, peak electricity demand, generation costs, greenhouse gas emissions, power plant siting constraints, and electricity reliability.

Water Resource Risk in the High Plains Region

Long Term Goal	• Delineate issues and mitigation strategies for risks associated with water resource management
FY2014 Goal	• Characterize the likelihood that the region (or parts of the region) that relies on the Ogallala Aquifer could face a permanent water shortage; • Assess the consequences to the existing population, economy, and critical infrastructure and possible ways that trends in water demands may impact those consequences; • Describe any current efforts to mitigate this threat, identifying responsible parties • Provide recommendations for areas of further analysis.
Project Partners	• NISAC • USDA, EPA, DOE, IP/SOPD • FEMA Regional Planners; Private sector owner/operators
Key Aspects	• Increased demand for water and energy in the region combined with the depletion of groundwater from the Ogallala Aquifer will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs. • Water policy (including pricing and prioritization of uses) is almost exclusively determined at the state level

Impact of Sea-level Rise on Hurricane Risk to CI

Long Term Goal	• Support risk-based decisions about critical infrastructure asset location and construction specifications with considerations to changes in geography, topography and bathymetry
FY2014 Goal	• Characterize the changes in risks to physical infrastructure under different sea-level-rise scenarios to quantify the impacts to population and the additional damage to infrastructure components due to hurricanes • Provide recommended mitigation strategies and best practices for industry.
Project Partners	• FEMA • DOE and other SSAs as appropriate • NOAA
Key Aspects	• Utilities tend to rebuild assets in the same location and to the same construction standards following damage from a hurricane. • Climate projections indicate increased incidence of severe storms and sea level rise. • If sea levels rise even a foot, then damage from storm surge could significantly increase and lead to increases in restoration and recovery times.

Drought Capability Development

Long Term CD Goal	• Ability to analyze and predict impacts of long-term droughts on critical infrastructure
FY2014 CD Goal	• Develop a framework drought analysis methodology • Analyze a drought scenario as a demonstration case • Analyze impact of drought on Pacific Northwest electric power generation
Project Partners	• DOE, FERC • Utilities (power and water)
Key Aspects	• Widespread drought impacts many critical infrastructure and the economy • Climate change increases the likelihood and severity of drought in the future • Analytic results can be used to support resource allocation and water use policy decisions to mitigate risks from drought

Homeland Security

For more information visit:
www.dhs.gov/office-cyber-infrastructure-analysis

DHS Climate Change Adaptation Roadmap

- DHS plans to protect and ensure the resilience of our critical infrastructure to potential impacts of climate change.
- Protection of critical infrastructure is essential to our Nation's prosperity, safety, and security. Climate change has the potential to impact all critical infrastructure sectors.
- Key potential impacts include the deterioration or failure of coastal infrastructure in the face of rising sea levels and storm surge, strains on power systems from increased population and energy use for cooling, possible dislocation of food production, and scarcity of water.
- DHS must work closely with the private sector, which owns and operates much of the Nation's critical infrastructure, as well as State and local governments.
- While the risks may seem distant, the lifecycle of infrastructure spans many decades, with service lives that may extend beyond 100 years.

Climate Change and Temperature

- Average temperatures in the U.S. have risen over 2°F in the past 50 years
- Greater warming will be experienced in the summer than in the winter, according to current projections
- The number of days above 90°F is projected to increase throughout the U.S.
- Average winter temperatures in the Midwest and Northern Great Plains have increased more than 7°F over the past 30 years
- Snowpack in the western mountains within the U.S. is projected to decrease with warming temperatures
  - Resulting in more winter flooding and reduced summer stream/river flows
  - Intensifying competition for water resources
- Heat waves will continue to challenge cities in the U.S. through increased number, intensity, and duration

Regional Economic Resiliency

Economic Impacts of Drought

If the regional economy in question has high concentrations of industry sectors reliant on water and water is unavailable to maintain system performance, the regional economy would be vulnerable to drought and less resilient.

- Three metrics of economic resilience can include:
  - *Impact on system productivity*
  - *Time to system recovery*–does not apply to chronic disruptions
  - *Costs*– price changes due to water scarcity

Homeland Security

Infrastructure Impacts from Increasing Temperature

COMMERCIAL FACILITIES	▪ Decreased snowfall and snow depths will reduce tourism and recreational activities dependent on snow, negatively impacting a $12.2 billion industry
COMMUNICATIONS	▪ Thawing permafrost in Alaska may cause tilting and sinking of communication towers ▪ Overheating of data centers, exchanges, and base stations will degrade system operability
CRITICAL MANUFACTURING	▪ Industrial equipment and machinery will be strained if not adequately cooled
DAMS	▪ Reduction in snowpack and increased snowmelt will decrease power generation capabilities, specifically in California ▪ Increased reservoir and river salinity will result from increased water evaporation corroding pipes and machinery
DEFENSE INDUSTRIAL BASE	▪ Changes in operational parameters may be necessary for weapons and equipment development and testing
EMERGENCY SERVICES	▪ Increased emergency response capacity may be needed due to increased human health impacts including heat-related illness and higher rate of disease transmission ▪ Emergency communications and response may be disrupted due to degradation of power infrastructure

THE WHITE HOUSE
WASHINGTON

PRESIDENT'S STATE, LOCAL, AND TRIBAL LEADERS TASK FORCE ON CLIMATE PREPAREDNESS AND RESILIENCE

Recommendations to the President

November 2014

About the State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience

The State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience (Task Force) was established by Executive Order 13653[1], *Preparing the United States for the Impacts of Climate Change,* on November 1, 2013. The President charged the Task Force with providing recommendations on how the Federal Government can respond to the needs of communities nationwide that are dealing with the impacts of climate change by removing barriers to resilient investments, modernizing Federal grant and loan programs to better support local efforts, and developing the information and tools they need to prepare, among other measures.

Co-chaired by the Chair of the White House Council on Environmental Quality (CEQ) and the Director of the White House Office of Intergovernmental Affairs (IGA), the Task Force consists of 26 governors, mayors, county officials, and tribal leaders from across the United States. Members brought first-hand experiences in building climate preparedness and resilience in their communities and conducted broad outreach to thousands of government agencies, trade associations, planning agencies, academic institutions, and other stakeholders, to inform their recommendations to the Administration.

The Task Force met in person on four occasions between December 2013 and July 2014 in Washington DC, Los Angeles, and Des Moines, to develop and refine their recommendations. Recognizing that climate change will affect virtually all aspects of the Nation's future, the Task Force focused on opportunities to build climate preparedness and resilience in key domains, including disaster recovery, infrastructure investment, natural resource management, human health, community development, and agriculture.

For more information about the State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience, please see: www.whitehouse.gov/administration/eop/ceq/initiatives/resilience/taskforce.

Cover Photos: Top Left: Vermonters celebrate the re-building of a historic covered bridge washed away by Tropical Storm Irene (2011). Photo Credit: *Bill Caswell, President, National Society for the Preservation of Covered Bridges.* Top Right: A home is left standing among debris from Hurricane Ike (2008) in Galveston County, Texas. Floodwaters from Hurricane Ike were as high as eight feet in some areas causing widespread damage across the coast of Texas. Photo Credit: *David J. Phillip-Pool/Getty Images.* Bottom Left: Lake Cachuma, in California, at 30% capacity under drought conditions. Photo Credit: *Lael Wageneck, County of Santa Barbara.* Bottom Right: Children in Philadelphia enhance local green stormwater infrastructure with spring plantings. Photo Credit: *Philadelphia Water Department.*

[1] See "Executive Order 13653: Preparing the United States for the Impacts of Climate Change", http://www.whitehouse.gov/the-press-office/2013/11/01/executive-order-preparing-united-states-impacts-climate-change

Task Force

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Michael Boots
White House Council on Environmental Quality

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Acknowledgements[2]

The Task Force's work benefited greatly from the contributions of its active and dedicated membership and their staff. Particular recognition is due to the members who chaired the Task Force's four subgroups: Governor Edmund Brown, Chairwoman Karen Diver, Commissioner Kristin Jacobs, Governor Jack Markell, Mayor Michael Nutter, Governor Peter Shumlin, and Mayor Karen Weitkunat.

Gratitude also goes to the Task Force designees and staff who led and supported the subgroup efforts: Louise Bedsworth, Kathy Dervin, Katherine Gajewski, Jennifer Jurado, Sarah McKearnan, Sue Minter, and Dan Weinhiemer.

The Task Force further extends its appreciation to the following leaders and contributors:

Founding co-chairs David Agnew, former Director of IGA and Nancy Sutley, former Chair of CEQ.

The IGA and CEQ staff who supported this effort, including Elias Alcantara, Shira Miller, and Susan Ruffo.

Members and staff of the interagency Council on Climate Preparedness and Resilience, whose participation in Task Force meetings and additional support and consultation was critical to this effort.

And a wide range of stakeholders from non-profits, think tanks, academia, the private sector, and state, local, and tribal government agencies and elected officials who work to make communities across the country resilient in the face of climate change and who shared their experiences with the Task Force and provided input that informed the development of these recommendations.

Task Force Members with Federal officials after meeting with President Obama, July, 2014. Photo Credit: *Shira Miller.*

[2] See Appendix C for additional acknowledgements.

THE WHITE HOUSE

WASHINGTON

Dear Mr. President,

We are pleased to share with you the recommendations of the State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience (Task Force) on how the Federal Government can better support local climate preparedness and resilience-building efforts, as called for in your Climate Action Plan. These recommendations reflect the collective opinions of the 26 Governors, mayors, county officials and tribal leaders who served on the Task Force, as well as the input they received from across State, local, tribal and territorial governments, private businesses, trade associations, academic organizations, civil society, and many other stakeholders.

As you know, climate change is already affecting communities in every region of the country and in key sectors of our economy. For example, Task Force members have dealt with catastrophic floods, fires, and drought. They have experienced flooding and erosion due to sea level rise, diminishing water storage in mountain snowpack, and loss of culturally significant crops and other resources. And they are not alone - leaders across the country face similar challenges. That is why, even as we take aggressive steps to cut the carbon pollution that drives climate change, we must act now to prepare for the impacts we can no longer avoid.

Task Force members have approached this challenge with creativity and pragmatism in their own communities, often making bold choices informed by the best available science, much of which originates in Federal agencies. They have invested in more resilient infrastructure, building smarter and stronger so their communities can withstand the next storm. They have adopted innovative stormwater management techniques that use green infrastructure to store water, strengthened building codes, and planned for rapid recovery from extreme weather events. The enclosed recommendations include examples of their specific successes and challenges we can all learn from.

The Federal Government has a critical role to play in supporting these efforts by establishing policies that promote climate preparedness, advancing science to help inform local actions, and protecting critical infrastructure and public resources. Over the past year, we have listened to their ideas and started taking action. This includes launching Federal grant competitions that encourage investments in community resilience and making vast Federal data resources on climate change impacts more accessible. The enclosed recommendations offer Task Force members' consolidated guidance on how the Federal Government can support communities by modernizing programs and policies to incorporate climate change, incentivizing and removing barriers to community resilience, and providing useful, actionable information and tools.

As you have made clear, responding to the threats of climate change requires bold action and collaboration across all levels of government. The enclosed recommendations will help guide the Administration as we continue our work to help build a safer, healthier, and more resilient Nation.

Sincerely,

Michael Boots
White House Council on Environmental Quality

Rohan Patel
White House Office of Intergovernmental Affairs

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Executive Summary

As the Third National Climate Assessment makes clear, climate change is already affecting communities in every region of the country as well as key sectors of the economy. Recent events like Hurricane Sandy in the Northeast, flooding throughout the Midwest, and severe drought in the West have highlighted the vulnerability of many communities to the impacts of climate change. In 2012 alone, the cost of weather disasters exceeded $110 billion in the United States, and climate change will only increase the frequency and intensity of these events. That is why, even as efforts to reduce greenhouse gas emissions continue, communities must prepare for the impacts of climate change that can no longer be avoided.

At state, local, tribal, and territorial levels, leaders are making bold decisions on ways to invest in more resilient infrastructure, revise land use, update building codes, and adjust natural resource management and other practices to improve the resilience of their communities to climate impacts. The Federal Government has a critical role to play in supporting these efforts by ensuring that Federal policies and programs incorporate climate change, incentivize and remove barriers to community resilience, and provide the information and assistance communities need to understand and prepare for climate risks. The Federal Government also has a responsibility to protect its own investments, such as military installations and space launch facilities, and ensure that the lands and resources it holds in the public trust are managed for a changing climate.

In order to better support communities across the country as they prepare for the impacts of climate change, the Task Force proposes that the Administration advance actions across the Federal Government that align with the following overarching principles:

- ❖ Require consideration of climate-related risks and vulnerabilities in the design, revision, and implementation of all Federal policies, practices, investments, regulations, and other programs.
- ❖ Maximize opportunities to take actions that have dual-benefits of increasing community resilience and reducing greenhouse gas emissions.
- ❖ Strengthen coordination and partnerships among Federal agencies, and across Federal, state, local, tribal, and territorial jurisdictions as well as economic sectors.
- ❖ Provide actionable data and information on climate change impacts and related tools and assistance to support decision-making at all levels.
- ❖ Consult and cooperate with Tribes and indigenous communities on all aspects of Federal climate preparedness and resilience efforts, and encourage states and local communities to do the same.

The diverse challenges posed by climate change will require a wide range of actions to ensure that communities across the country, large and small, are prepared. With coordination, thoughtful planning, and decisive action, Federal, State, and local governments, Tribes, and territories can ensure a safe and prosperous future.

Summary of Recommendations

1. Building Resilient Communities: Climate change will impact communities for years to come, and long-term efforts to build resilience will help communities thrive in the 21st century and beyond. By incorporating climate change considerations into its programs, the Federal Government can support communities as they rethink traditional approaches to land use and land management, building and infrastructure siting and design, and community planning.

2. Improving Resilience in the Nation's Infrastructure: Climate change poses a significant threat to the safety and reliability of critical infrastructure systems. Whether related to energy, transportation, freshwater management, coastal protection, or ecosystems, Federal action can improve the way climate impacts and greenhouse gas emissions are incorporated into public and private infrastructure investments, policies, and practices.

3. Ensuring Resilience of Natural Resources: Climate change puts America's vital natural resources and ecosystems at risk. By helping communities better protect and conserve the Nation's natural resources, the Federal Government can improve human and community resilience in cost-effective ways.

4. Preserving Human Health & Supporting Resilient Populations: Climate change presents a significant public health threat to individuals and communities, exacerbating illness and increasing the frequency and severity of dangerous extreme weather events. The Federal Government can support State, local, tribal, and territorial efforts to address the needs of populations most vulnerable to climate impacts, protect public health, and improve disaster preparedness.

5. Supporting Climate-Smart Hazard Mitigation and Disaster Preparedness and Recovery: Climate change will increase the frequency and severity of extreme weather events, which are often devastating to communities. Through more holistic hazard mitigation planning, improved data collection and mapping, partnership development, and program modernization, the Federal Government can improve efforts to prevent and mitigate the effects of extreme weather and other climate-related hazards.

6. Understanding and Acting on the Economics of Resilience: Climate change poses significant economic risk to all sectors and communities. Advancing measures to encourage more prudent investments in long-term resilience can better ensure a vibrant economic future as the climate continues to change.

7. Building Capacity for Resilience: To successfully prepare for climate change, communities must have the capacity to recognize, understand, and assess relevant climate-related hazards, risks, and impacts. The Federal Government can help communities build this capacity by continuing to shape or reshape programs, policies, information sources, and other forms of assistance that enable state, local, tribal, and territorial jurisdictions to prepare for climate change.

Additionally, the Federal Government should establish a process for tracking and reporting on progress made in the implementation of the recommendations, as well as specific benchmarks.

Introduction: A Call to Prepare for Climate Change Impacts

"Climate change, once considered an issue for a distant future, has moved firmly into the present."
- First Key Finding of the Third National Climate Assessment[3]

Across the United States, communities—large and small, urban and rural—are on the front lines of climate change. Increased warming, drought, and insect outbreaks, caused or exacerbated by climate change, have increased wildfires and other impacts on people and ecosystems in the Southwest. Extreme rainfall events and flooding have increased in the Midwest over the last century, degrading water quality and negatively impacting transportation systems and other infrastructure, agriculture, and human health. Heat waves, more extreme rainfall, and coastal flooding due to sea level rise and storm surge are expected to increase in the Northeast and Gulf Coast regions. Thawing of permafrost in the Arctic and rising sea levels and reduced freshwater supplies in the Pacific are also expected to worsen in the future.

Snapshot of projected climate impacts

- By mid-century, the infrastructure investments needed to combat rising temperatures in the Midwest will require more than $6 billion. "Further, approximately 95% of the electrical generating infrastructure in the Midwest is susceptible to decreased efficiency due to higher temperatures."[4]
- Across the North Atlantic states, cumulative costs of sea-level rise and associated flood damage may exceed $88 billion by 2100.[5]
- As much as 40% of reef-associated fish may be lost due to massive coral disease outbreaks, associated with higher water temperatures, in the Hawaiian archipelago, impacting $385 million in associated goods and services for Hawaii alone.[6]
- For California and other states across the Southwest climate change will increase the cost of maintaining and improving drinking water infrastructure by increasing the need for wastewater treatment and water desalination to supplement water supplies; even without the costs of these preparedness measures, California's drinking water system alone will require more than $4 billion in investment per year for the next 10 years.[7]
- In Alaska, thawing and sinking of once frozen ground may cost between $3.6 and $6.1 billion (10% to 20%) above current public infrastructure maintenance over the next 20 years. In more rural parts of Alaska, such permafrost thaw is likely to disrupt community water supplies and sewage systems, posing risks to residents' health.[8]

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[3] See Melillo, J.M., Richmond, T.C., and Yohe, G.W. Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, pp. 148. http://nca2014.globalchange.gov
[4] See Pryor, S. C., et al. "Ch. 18: Midwest" *Climate Change Impacts in the United States: The Third National Climate Assessment*, http://nca2014.globalchange.gov/report/regions/midwest
[5] See Moser, S.C., et al. "Ch. 25: Coastal Zone Development and Ecosystems" *Climate Change Impacts in the United States: The Third National Climate Assessment*, http://nca2014.globalchange.gov/report/regions/coasts
[6] See Leong, J.-A., et al. "Ch. 23: Hawai'i and U.S. Affiliated Pacific Islands." *Climate Change Impacts in the United States: The Third National Climate Assessment*, http://nca2014.globalchange.gov/report/regions/hawaii-and-pacific-islands
[7] See Garfin, G. et al. "Ch. 20: Southwest." *Climate Change Impacts in the United States: The Third National Climate Assessment*, http://nca2014.globalchange.gov/report/regions/southwest
[8] See Chapin, F. S., III, et al. "Ch. 22: Alaska" *Climate Change Impacts in the United States: The Third National Climate Assessment*, http://nca2014.globalchange.gov/report/regions/alaska

To address the root causes of these challenges, leaders at all levels of government and in the private sector are acting to reduce greenhouse gas emissions. Significant reductions in these emissions are needed in order to slow the effects of climate change before it becomes too difficult and expensive for nations and communities to adequately prepare for anticipated climate impacts. But carbon pollution has been building in our atmosphere for decades, so even as we act to reduce the emissions of greenhouse gases that drive climate change, we must also prepare our communities for the impacts that can no longer be avoided.

Anticipating and planning for these impacts now can reduce the harm and long-term costs of climate change to communities. Decisions made today about where and how communities grow, the infrastructure they build, and the codes and standards they adopt will affect them long into the future, so decision-makers must take climate change into account as they plan. In doing so, there must also be a particular focus on helping the most vulnerable populations prepare, since they are likely to be disproportionately affected. This will require thoughtful planning and capacity building, including the development and timely delivery of science, information, analytical tools, and practical, cost-effective measures and technologies that can help deal with future climate conditions. Coordinated action by all levels of government, businesses, individual citizens, and others will be crucial.

"In April 2014, severe flooding in Alabama resulted in widespread damage throughout Baldwin County, including the Town of Perdido Beach. In our tiny town surrounded on three sides by estuarine water bodies, every street was damaged and three were impassable, cutting off an entire neighborhood until emergency work could be done to restore passage. Unable to handle the 25 inches of torrential rain that fell over a period of two days, numerous homes were flooded and extensive damage occurred to our infrastructure. Fortunately, recovery assistance came by way of State and Federal aid. While post-disaster assistance is much needed and appreciated, local leaders need support to plan for future extreme weather impacts before they occur."

- **Mayor Patsy Parker, Perdido Beach, Alabama**

Flood damage in Perdido Beach, AL.
Photo Credit: *Patsy Parker, May 2014.*

Current Actions to Prepare for Climate Change

From repeated low level flooding and extreme storms to increasing temperatures and drought, climate change hits every community differently. State, local, tribal, and territorial leaders are at the forefront of dealing with these impacts and preparing their communities for future changes. These leaders recognize the need to act now to protect their communities, and are doing so with their own authorities and resources while working with diverse partners including business, community organizations, various levels of government, and citizen groups.

Examples of innovative and forward-thinking leadership can be found in communities across the country. For example, the City of Houston has created a network of mobile solar-powered community support and disaster response stations that can operate off the electric grid and provide basic needs to the community in the aftermath of major disasters; communities from Vermont to Des Moines and Fort Collins to Fond du Lac Reservation have recovered from severe floods and storm damages by rebuilding roads and other infrastructure with specific designs for better withstanding future hazards; four counties in Southeast Florida joined together to establish a coordinated planning effort to adapt to sea level rise; and low-lying states like Delaware and Maryland have established requirements for state-funded construction projects to be designed to accommodate future sea level rise and increased flooding.

"Cities are at the frontlines of climate change and must deal with its consequences through effective actions. Grand Rapids has faced the impacts of floods, heat waves, and snow blizzards in the last three years. State and Federal governments need to provide support to local governments and ensure coordinated efforts to address climate change effects."

- **Mayor George Heartwell**
  Grand Rapids, Michigan

The Federal Government has an essential and unique role to play in supporting these efforts. Through funds that help to build and repair critical infrastructure such as roads, bridges, and water treatment plants, regulations that ensure clean air and clean water, support for disaster recovery, and programs that promote public health and economic development, the Federal Government works with States, local governments, Tribes, and territories to ensure that communities across the country are safe and prosperous. As part of their work to achieve these diverse missions, Federal agencies can support local efforts to build climate resilience by providing vital leadership, guidance, and information, and by adjusting their programs to encourage preparedness and recognizing and removing barriers to local initiatives. Because climate impacts are felt locally but require action across political boundaries, these actions must involve partnerships with multiple jurisdictions, and the Federal Government can promote such coordination.

The Federal Government should also lead by example in its own efforts to prepare for climate change impacts. According to a 2013 Government Accountability Office (GAO) report[9], climate change increases Federal exposure to risk in several areas, including as the owner/operator of infrastructure such as defense facilities and other property, the provider of disaster recovery assistance, and the insurer of property and crops vulnerable to climate impacts. The Federal Government can address climate impacts in these areas, and on the natural, cultural, and historic resources it has statutory responsibilities to protect. Federal actions to prepare for climate change impacts on missions, programs, and operations will ensure that government services remain effective despite a changing climate. These actions will also ensure that taxpayer and other national resources endure and are invested wisely. It is critical that these efforts are coordinated with state, local, tribal, and territorial partners.

Hurricane Sandy coastal flooding in Mantoloking, NJ.
Photo Credit: *New Jersey National Guard/Scott Anema.*

[9] "High Risk Series: An Update" *U.S. Government Accountability Office*, GAO-12-283. February 2013. http://www.gao.gov/products/GAO-13-283

Task Force Recommendations

The Task Force has developed the following recommendations on key actions the Federal Government can take to better support state, local, tribal, and territorial leaders working to prepare their communities for the impacts of climate change. These recommendations focus on opportunities to remove barriers to resilient investments, modernize Federal grant and loan programs to better support and encourage local efforts, and develop the information and tools that decision makers need to understand and prepare for the impacts of climate change. Recommendations are organized across seven themes: Building resilient communities; improving resilience in the Nation's infrastructure; ensuring resilience of natural resources; preserving human health and resilient populations, supporting climate-smart hazard mitigation and disaster preparedness and recovery, understanding and acting on the economics of resilience, and building capacity for resilience.

Overarching Principles

The following overarching principles represent common threads in the Task Force discussions and recommendations, and provide high–level guidance for efforts to build National climate preparedness:

1. Require consideration of climate-related risks and vulnerabilities as part of all Federal policies, practices, investments, and regulatory and other programs.
Current Federal programs, policies, investments, and assistance mechanisms do not fully account for climate vulnerabilities and risks, resulting in Federal investments in Federal, state, local, tribal, and territorial projects that may not be appropriately designed to withstand or address potential climate-related impacts. Taxpayer dollars spent on projects that do not consider these impacts in design or execution could be wasted.

Federal programs can drive more resilient community choices by:

- Prioritizing Federal investments toward more resilient projects and disallowing Federal investments that would increase risk or vulnerability;
- Ensuring that all disaster recovery projects funded with Federal dollars are cost-effective and designed and built to avoid and withstand future climate impacts;
- Ensuring that all infrastructure and other long-lived investments made with Federal dollars are designed to be effective, accessible, and operational under future climate conditions;
- Encouraging innovative approaches that leverage private capital and existing assets; and
- Providing technical assistance to States, territories, Tribes, and communities that lack capacity to adapt to climate change.

Learning from Hurricane Sandy Resilient Rebuilding

The work of the Hurricane Sandy Rebuilding Task Force and of the many Federal agencies that provided assistance for recovery and rebuilding in the region affected by the storm demonstrate early advances in revamping Federal programming to consider resilience. For example, the Department of Housing and Urban Development (HUD) required that all of its grantees assess their vulnerabilities to current and future risks and show how they would address those risks, while the Department of Transportation (DOT) provided $3.6 billion for projects designed to increase the resilience of the transportation systems in the affected region.[10] These and other such practices can ensure responsible use of Federal dollars—a smart policy in any case, but especially important in an era of constrained resources.

[10] "Notice of Funding Availability for Resilience Projects in Response to Hurricane Sandy" *U.S. Department of Transportation,* FTA-2013-006-TPM. Federal Register, 78(248). 26 December 2013. http://www.fta.dot.gov/grants/13077_15783.html

2. Maximize opportunities to take actions that have dual-benefits of increasing community resilience and reducing greenhouse gas emissions.

Reducing greenhouse gas emissions will ultimately limit the impacts of climate change on communities. As communities develop strategies to prepare and withstand the impacts of climate change, these solutions should, where possible, utilize actions that complement or directly support efforts to reduce greenhouse gas emissions. Particular emphasis should be placed on opportunities presented by planning decisions and investments in areas including:

- The nexus between increasing demand for water for energy production and the extraordinary energy demand associated with the treatment and movement of water;
- The climate resilience and energy efficiency of transportation systems that support sustainable development and also reduce carbon emissions and related pollutants;
- Energy systems that are cleaner and more efficient, in addition to more climate-resilient; and
- The health of natural systems that provide resilience services like buffering of coastal and riverine flooding and stormwater management, while also providing mitigation benefits, including carbon sequestration and storage.

3. Strengthen coordination and partnerships among Federal agencies, and across Federal, state, local, and tribal jurisdictions and economic sectors.

The challenges posed by a changing climate cross the traditional boundaries of government agencies, economic sectors, politics, and geography. So-called "silos" among and within Federal agencies must be removed to ensure alignment of policies, practices, and resources for climate resilient planning and projects, and local voices should be at the table during development of locally relevant initiatives to ensure they have the intended effect. The Federal Government can also play an important role in promoting cooperation across jurisdictions, regions, and at multiple levels of government in order to ensure an integrated approach. As governments cannot solve these problems alone, private sector and other stakeholder involvement should be encouraged.

4. Provide actionable data and information on climate change impacts and related tools and assistance to support decision-making.

To make climate-smart planning and investment decisions at a regional, state, tribal, territorial, and local level, decision-makers need access to the best available information about climate impacts in a user-friendly and accessible format. Building on successful efforts like the National Oceanic and Atmospheric Administration's (NOAA) Regional and Integrated Sciences and Assessments program, more can be done to provide authoritative, consistent, and relevant information and tools to help inform planning and decision making at all levels.

Western Water Assessment
Salt Lake City, Utah

The Western Water Assessment (WWA)[11], based at the University of Colorado Boulder, is a program of NOAA serving Colorado, Utah, and Wyoming with climate data and research partnerships. In 2009, WWA placed a liaison in Salt Lake City, and has since partnered with Salt Lake City Municipal and universities in Utah and Wyoming to develop climate models and conduct vulnerability assessments to help the City identify climate change scenarios on a much needed local and community scale. The work is made available, through synthesis and real-time climate information interfaces, to other communities as well, allowing for dissemination of decision-relevant information.

[11] See http://wwa.colorado.edu/

5. Consult and cooperate with Tribes and indigenous communities on all aspects of Federal climate preparedness and resilience efforts, and encourage States and local communities to do the same. Through targeted and widespread engagement with Tribal, Alaska Native, and Pacific Island indigenous communities by Task Force members and Federal agency partners, consensus emerged around recommendations to support tribal and indigenous communities in preparing for the unique impacts they face as a result of climate change. The Federal Government must fully incorporate its government-to-government relationship with Tribes and Alaska Native communities into existing programs and activities that relate to climate change by enhancing self-governance capacity, promoting engagement of State and local governments with tribal communities, and recognizing the role of traditional ecological knowledge in understanding the changing climate.

> *"Responding to climate change must be a shared responsibility that shouldn't be constrained by our respective political boundaries, geographical locations or cultures. Minnesota experienced torrential rains and heavy flooding in 2012, and the Fond du Lac Reservation was heavily impacted. The Tribe learned the hard way that the many jurisdictions involved had not sufficiently coordinated their emergency planning. As roads were damaged and neighborhoods were isolated, we had to figure out on our own how to evacuate and house displaced residents. We have since learned that our response could have been faster and more efficient with the assistance that other agencies could have provided. Similarly, we learned that the Tribe's emergency response assets would have been helpful to others. We know now that we need to work harder to engage in multi-jurisdictional planning to best serve all our citizens."*
>
> - **Karen Diver, Chairwoman, Fond Du Lac Band of Lake Superior Chippewa**

Informed by the overarching principles above, the Task Force offers the following specific recommendations across seven themes.

Theme 1: Building Resilient Communities

Resilience is a key characteristic of thriving communities in the 21st century and beyond. The impacts from a changing climate will stress infrastructure, strain social networks, hamstring economies, and tax available resources. Communities that are unprepared for these challenges may be irreparably harmed. By contrast, resilient communities will benefit not only from greater climate security, but also improvements to quality of life thanks to the multiple benefits of climate preparedness activities. For example, strategic tree-planting initiatives in cities facing hotter climates can help reduce temperatures while also providing well-documented improvements to air quality, increases in neighborhood property value, decreases in public health costs, and reductions in energy demand.[12] Utilities and communications systems, hard and soft infrastructure systems, social services, public and private property, agriculture and food—these and many more of the systems that support modern life will need to be revamped, redesigned, and rebuilt with resilience in mind.

Developing resilient communities means more than just building in a way that allows for rapid recovery from and avoidance of future disasters. Resilient communities provide an exceptional quality of life. Characteristics of these communities include clean and abundant water supplies protected for future generations, and energy systems powered by fuels that do not exacerbate climate change or damage public health and are reliable even when disaster strikes. In addition, resilient communities enable more efficient forms of transportation like walking or bus and rail transit, yielding public health benefits.

Forward-looking and informed planning is also a critical component of ensuring that communities are prepared for climate impacts. Siting and designing buildings and infrastructure for long-term climate resilience can improve cost-effectiveness by helping ensure continuity of operations and minimizing recovery costs after a disaster. Federal agencies are already playing a pivotal role in incentivizing and helping to share model approaches to holistic, resilience-focused planning. The following recommendations offer ways the Federal Government can continue to facilitate more systemic infrastructure planning and project design and construction, address climate-related hazards, and help State and local governments, Tribes, and territories build more resilient communities.

Vermonters celebrate the re-building of a historic covered bridge washed away by Tropical Storm Irene (2011).
Photo Credit: *Bill Caswell, President, National Society for the Preservation of Covered Bridges.*

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[12] See documentation of these and other benefits at:
http://depts.washington.edu/hhwb/Top_References.html#Local%20Economics and
http://www.houstonregionalforest.org/Report/

1.1 Accelerate the development of models and disseminate best practices for community resilience.
Federal agencies are already playing a pivotal role in sharing and incentivizing model approaches to sustainability across the country with programs like the interagency Partnership for Sustainable Communities led by HUD, DOT, and the Environmental Protection Agency (EPA). These efforts should be broadened to demonstrate how communities can integrate sustainability and climate resilience, and encourage replication of successful models.

> *"In the planning and rebuilding process after the May 2007 tornado, Greensburg citizens met at community meetings to plan the future. This process allowed us to address systematic problems that could be corrected in the rebuild. Sustainability and rebuilding 'green' were the focus of being a resilient community."*
> - **Mayor Bob Dixson, Greensburg, Kansas**

Actions to advance this recommendation include:

1.1.1 Expand the Partnership for Sustainable Communities and other place-based programs to explicitly incorporate and encourage climate resilience by supporting the development of local laboratories where approaches to sustainable and resilient energy, infrastructure, transportation, flood proofing, natural infrastructure, etc. can be tested and disseminated more broadly.[13]

1.1.2 Collaborate across Federal agencies to provide services and promote channels for sharing climate resilience best practices and lessons learned, including peer-to-peer learning among States, local communities and Tribes, and workshops, training, and interactive web resources.

Vermont and Colorado Peer Exchange

In September 2013, Colorado experienced an unprecedented eight-day rain resulting in devastating flooding and destruction. The event affected about 1,500 square miles leaving more than six thousand people evacuated, thousands of homes and businesses destroyed or damaged, dozens of bridges destroyed, and approximately 200 miles of roads impassable. Through a relationship between their Governors, Vermont officials came to advise Colorado officials on transportation system recovery and how to work through the Federal Highways Administration (FHWA) and Federal Emergency Management Agency (FEMA) recovery processes. This policy exchange is credited with speeding Colorado's recovery; all roads were rebuilt and opened to a temporary functioning before December 2013.

1.2 Develop and encourage adoption of resilience standards in the siting and design of buildings and infrastructure.
The Federal Government should play a leading role in developing and encouraging the use of resilience guidelines and standards across sectors and throughout the built environment.[14] Federal participation in the establishment of such standards for climate resilience would encourage adoption by the private sector, other levels of government, and nongovernmental organizations, ultimately accelerating integration of climate resilience measures across sectors and communities.

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[13] See for example, the Climate Action Champions Competition, launched in October 2014. The competition builds on the momentum of ongoing place-based initiatives to recognize innovation and leadership by local and tribal governments in reducing carbon pollution and preparing for the impacts of climate change. http://www.whitehouse.gov/blog/2014/10/01/recognizing-american-communities-climate-action-champions

[14] The Federal Government has contributed to the widespread adoption of standards, such as Leadership in Energy & Environmental Design (LEED), by adopting such standards for its own operations.

Actions to advance this recommendation include:

1.2.1 Establish guidance and, where appropriate, minimum standards, to help achieve consistency in the consideration and treatment of climate resilience as part of project planning, design, and construction. Federal incentives can be used to encourage State and local governments, Tribes, and territories to adopt resilience standards, and to use higher standards when rebuilding in the wake of disasters.

1.2.2 Federal agencies should adjust their practices in and around floodplains to ensure that Federal assets will be resilient to the effects of climate change, including sea level rise, more frequent and severe storms, and increasing river flood risks, as called for in the President's Climate Action Plan. Projects that receive Federal funding should be sited and designed with the best-available climate data and include margins of safety, such as freeboard and setbacks, to account for uncertainties and reduce costs and disruption from future hazards.

High tide flooding in Broward County, Florida. Photo Credit: *Paul Krashefski.*

1.3 Encourage and reward climate-smart land use management and development practices.

Federal policies and programs should provide incentives and technical assistance to support climate-smart land use and development that actively assesses and manages climate-related risks. State and local governments, Tribes, and territories that employ such practices should receive preferential consideration, a greater Federal cost share and/or more favorable financing terms from Federal programs that fund infrastructure, community, and housing development. Cost shares or interest rates could be more favorable, for example, for those communities that adopt freeboard, strong building codes, or floodplain and coastal setbacks; join the National Flood Insurance Program (NFIP) Community Rating System; or prohibit new critical facilities and other high-consequence activities in the 500-year floodplain. As much as possible, the incentives should be similar across Federal programs so that recipients are consistently rewarded for similar actions.

Actions to advance this recommendation include:

1.3.1 Federal agencies should consider strategies within existing grant programs to facilitate and explicitly encourage integrated hazard mitigation approaches that incorporate climate-change-related risks, land use, and capital improvement planning.[15]

1.3.2 Use strategies for pooling resources across agencies and simplifying planning and other programmatic requirements, which often over-burden communities, to help build state, local, tribal, and territorial capacity and encourage climate-smart land use policies while optimizing efficiencies.

[15] Incentives could be added to FEMA's Hazard Mitigation Grant Program, HUD's Community Development Block Grant program, the Department of Commerce's Economic Development Administration grants, EPA's State Revolving Loan Funds, US Department of Agriculture's (USDA) Rural Development grants, and US Army Corps of Engineers (USACE) programs, among others.

1.3.3 In order to support climate-smart land use in smaller and more rural communities, the NFIP Community Rating System should include application and reporting processes that are designed for communities that may lack the capacity to meet the current program's administrative requirements.

1.4 Lead by example: The Federal Government should serve as a model for climate resilience in its investments, operations, and programs.

Federal Government facilities and operations should serve as models for climate resilience by ensuring that climate impacts are taken into account in all stages of facility planning, design, construction, and management. Water, energy, and other resource demands associated with Federal activities should also be evaluated and planned for in light of projected changes in climate and in cooperation with local and regional managers and community officials. This process would protect the Federal Government's investments in its facilities and the economic benefits they provide to regions. It would also help protect the water resources and ecological health of regions in the face of a changing climate, and promote sustainable land use planning.

Actions to advance this recommendation include:

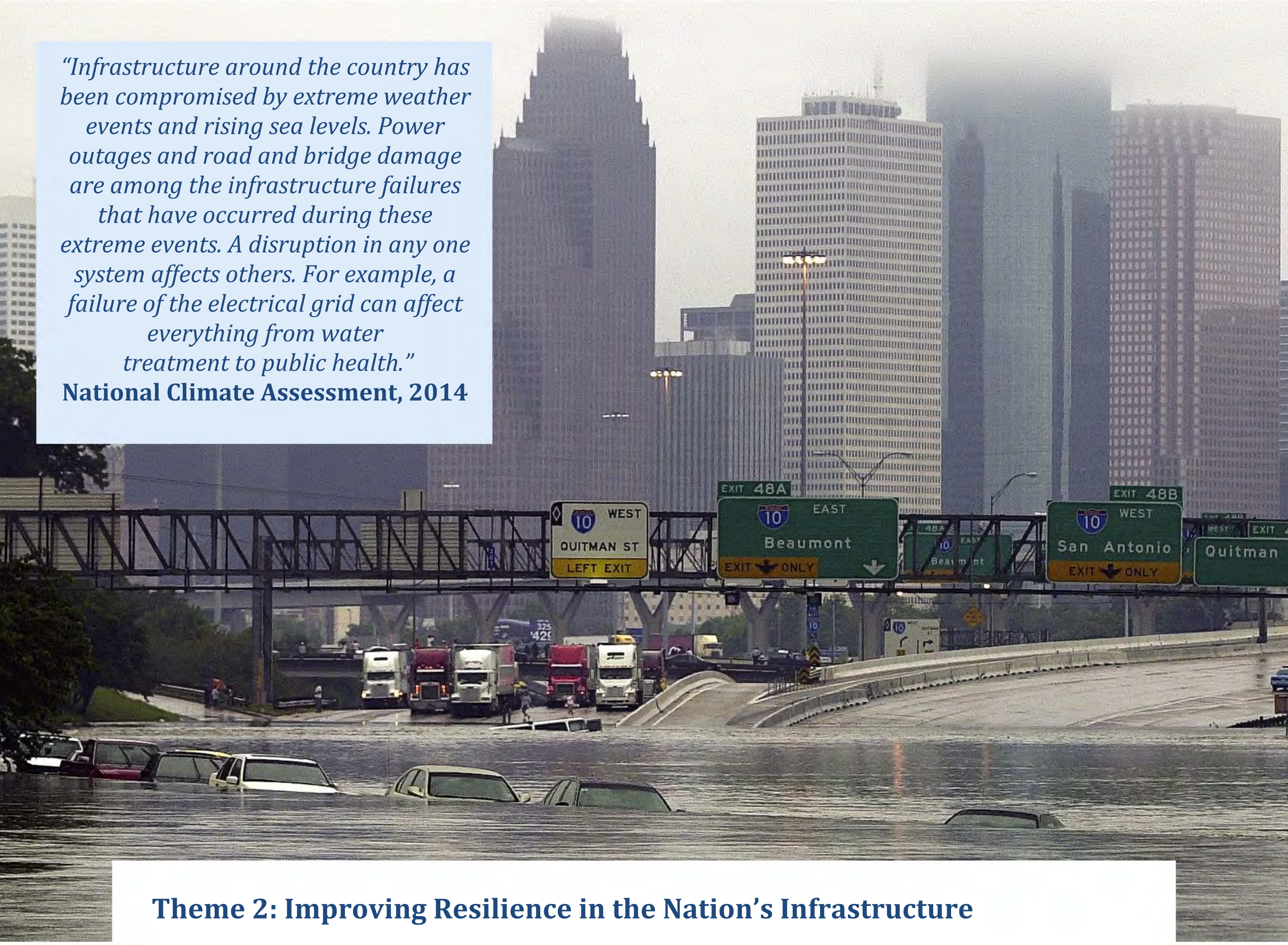
1.4.1 Commit to the incorporation of resilient design standards in the building, retrofit or repair of Federal facilities and projects and investments on Federally-owned property.

1.4.2 Maximize the use of natural infrastructure designs in all Federally-funded capital projects.

1.4.3 Employ resilient distributed energy generation for Federal facilities, where feasible, as part of the President's 20% by 2020 renewable energy goal.

> *"One of the first sustainability resolutions in the nation was adopted in Franklin County, Ohio in 2006. Citing the mutual compatibility of economic development and environmental protection, the policy is embedded in all county budgeting, leading to LEED Gold construction of several community institutions, reducing cost by saving energy and extending building lifetime. Similar approaches should be taken to integrate climate preparedness measures throughout local planning."*
>
> - **Commissioner Paula Brooks, Franklin County, Ohio**

"Infrastructure around the country has been compromised by extreme weather events and rising sea levels. Power outages and road and bridge damage are among the infrastructure failures that have occurred during these extreme events. A disruption in any one system affects others. For example, a failure of the electrical grid can affect everything from water treatment to public health."
National Climate Assessment, 2014



Theme 2: Improving Resilience in the Nation's Infrastructure

Climate change threatens the safety and reliability of the infrastructure systems that local economies and community security depend upon. Climate change impacts water delivery and wastewater treatment systems; flood risk management infrastructure; rail, road, and port infrastructure; natural infrastructure; energy production and distribution systems; and critical facilities, highlighting the interdependence of these systems and affecting social and economic activity in public and private sectors. Federal investments, activities, and policies must seek to reduce vulnerability of public and private infrastructure to sea level rise, recurrent flooding, storm surge events, coastal erosion, and other climate change related impacts through incorporation of such risks into siting, design, repair, and management of critical infrastructure.

The following recommendations offer ways that the Federal Government can align investments, policies, and practices to reduce the vulnerability of public and private infrastructure to climate impacts, including through better planning and siting, and improving the resilience of infrastructure that cannot be relocated from vulnerable areas.

Overflow from White Oak Bayou spilled onto Interstate 45 near Quitman Street after remnants of Tropical Storm Allison inundated Houston, Texas. Photo Credit: *Smiley N. Pool/Houston Chronicle.*

2.1 Support climate resilience as part of coastal infrastructure planning and investments.
A significant portion of the Nation's population, economic activity, and infrastructure is located near the coast, in floodplains, or in other areas vulnerable to sea level rise, more intense storms, tides, and coastal erosion. Remote communities, including small islands and some Alaska-Native villages, are especially vulnerable. Federal programs must better take into account both the importance and vulnerabilities of these areas when providing guidance or resources. For example, in July 2014, NOAA announced new program guidance[16] for state coastal management programs to ensure greater consideration of how climate change may exacerbate challenges in the management of coastal areas. Building off of this important step, additional actions to help advance this goal include:

2.1.1 The USACE should conduct coastal climate vulnerability assessments of all of its districts and disseminate this information to communities to enable cross-jurisdictional resilience planning.
2.1.2 Support efforts by facility managers for ports, harbors, inland navigation waterways, and coastal highways, to identify and address climate vulnerabilities. Make resilience planning a requirement for Federal support for ports, harbors, and inland waterways used for navigation, and for coastal highways, including congressionally authorized channel and navigation improvement projects.
2.1.3 Increase Federal support for local sea level rise and coastal erosion research and planning, and implement strategies that address both current and future impacts of climate change on coastal and Great Lakes ecosystems and communities. This should include improved agency coordination and transparency in the planning, review, and permitting of shoreline projects.
2.1.4 Provide technical assistance to assist coastal and island communities as they develop response plans and strategies for sea level rise, increased storm surge, and other climate change related risks.
2.1.5 Expand the use of the USACE's regional sediment management programs, where appropriate, to address coastal erosion threats in a comprehensive and cost-effective manner.

Coast Smart Communities Program
State of Maryland

Maryland's shorelines extend over 3,000 miles along the diverse landscapes of the Chesapeake Bay, the Coastal Bays, and the Atlantic Ocean. These landscapes are highly susceptible to coastal storms, flooding, and hurricanes, and are vulnerable to the long-term effects of a changing climate. Supported by NOAA's Coastal Zone Management program, the CoastSmart Communities[17] program connects local planners to information, tools, people, grants, and trainings to assist local communities in addressing short- and long-term coastal hazards, such as coastal flooding, storm surge, and sea level rise. To date, CoastSmart has funded more than twenty local government projects, all aimed at increasing overall resilience to coastal hazards in Maryland.

2.2 Promote and prioritize the use of green and natural infrastructure.
Natural systems are important features within the built environment, providing buffers against flood impacts and storm surge, storing water and recharging aquifers, helping to manage stormwater and moderate local temperatures, and providing vital habitat for native and migratory wildlife. Green infrastructure, also called natural infrastructure or natural defenses, for example wetlands, healthy reefs, living shorelines, dunes, floodplains, and forests, can mitigate risks to life and property while providing other social, economic, and environmental benefits, including carbon sequestration. Utilizing

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[16] See "NOAA Coastal Zone Management Act," http://coastalmanagement.noaa.gov/backmatter/media/guidancefy14309.pdf
[17] See "Maryland Department of Natural Resources: CoastSmart Communities," http://dnr.maryland.gov/coastsmart/

green infrastructure alongside traditional infrastructure can help communities, public agencies, and private industry prepare for and respond to climate change in a cost-effective manner, and enhance natural and social systems. The Federal Government should facilitate planning and financial support for the protection, creation, and restoration of natural infrastructure to enhance environmental benefits and mitigate future risks from a variety of climate hazards.

Coastal ecosystem restoration project, New York City. Photo Credit: *NCA, Department of City Planning.*

Actions to advance this recommendation include:

2.2.1 Require that project scoping for federally funded transportation, water, energy, and other infrastructure investments include evaluation of natural infrastructure, alone or in combination with engineered or "gray" measures, to address issues such as coastal protection, stormwater runoff, and flood storage.

2.2.2 Provide tools, resources, best practices, case studies, engineering guidelines and incentives to help jurisdictions consider and utilize green infrastructure as a strategy for managing climate change impacts that maximizes environmental, social, and economic benefits, and protects natural systems.

2.2.3 Federal policies and programs should seek to identify, protect, and maintain ecological features such as forests and wetlands that may serve to buffer Federally funded infrastructure projects from climate impacts, remove regulatory and administrative barriers to restoration and maintenance of natural systems that help increase or maintain community resilience, and promote the use of traditional ecological knowledge and management features in resilience strategies.

2.2.4 Adjust Federal project funding and grant programs to ensure that the use of natural infrastructure to wholly or partially buffer facilities and infrastructure from climate impacts is an eligible activity, and encourage this practice as appropriate.

2.2.5 Encourage States, local governments, Tribes, and territories to fully implement the 20% set-aside for green infrastructure projects under the EPA State Revolving Fund programs, including through updated and enhanced guidance. The EPA should also consider increasing the percent set-aside allowable for green infrastructure.

2.2.6 Revise the new policy allowing "waterway channelization and erosion projects" to be funded under FEMA's mitigation funding programs in order to clarify that floodplain restoration projects to reduce erosion are fundable under this policy, and to add a requirement that project applicants investigate non-structural, green infrastructure approaches to flood risk management and utilize them to the greatest extent practicable before resorting to structural solutions.

Natural infrastructure from coast to coast

Across the country, states with coastal exposure are taking steps to utilize natural infrastructure to protect coastlines and enhance resilience. For example:

- In Florida, examples of natural infrastructure solutions include wave-breaking coral reefs, wave-absorbing beaches and dunes, and flood attenuating coastal wetlands, as well as natural/engineered hybrid features generally called living shorelines.
- In 2008, the Maryland legislature enacted the Living Shoreline Protection Act. The Act requires riparian property owners to rely upon "living shorelines" (defined as nonstructural shoreline stabilization measures such as marsh creation), whenever feasible, to protect shorelines from erosion while also providing critical wildlife habitat. A variety of State agencies in Maryland are involved in implementing the program and related efforts.
- In March 2014, the Washington State Department of Ecology released its "Soft Shoreline Stabilization" guidance,[18] which assists local government staff in planning and implementing shoreline stabilization provisions within Shoreline Master Programs. This guidance provides an introduction to common shoreline stabilization impacts and applicable regulations, describes the underlying intent of soft stabilization management policies, and identifies key considerations for soft shoreline planning and permitting, including project challenges.

2.3 Support and incentivize climate resilient water resource planning and management.[19]

The water sector is vulnerable to climate change through more intense droughts, extreme storm events, shifting precipitation, loss of mountain snowpack, Great Lakes water level decline, sea level rise, ecosystem changes, degradation of supply, storage, and delivery infrastructure, temperature rise, and other impacts. The Federal Government must support and incentivize climate-smart water resource planning and management, in all regions and at all levels of government.

2.3.1 Expand Federal agency collaborations with State and local governments, Tribes, territories, and regional entities to evaluate the long-term risks of climate change on water resource availability and in the development of sustainable water resource plans and management strategies. Activities could include sharing of data, costs, personnel, and resources, using models such as the Silver Jackets Program led by USACE or the Service First partnership between the U.S. Forest Service and Department of Interior (DOI). Applicable agencies include EPA, DOI (including the Bureau of Reclamation), and USACE.

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[18] See "Washington Department of Ecology: Shoreline Master Program Planning and Implementation Guidance," https://fortress.wa.gov/ecy/publications/publications/1406009.pdf

[19] See related recommendations on protecting water quality and quantity (3.5) and Promoting green and natural infrastructure (2.2).

2.3.2 Provide technical support and guidance on how to conduct assessments of the vulnerability of water infrastructure to climate change impacts and incorporate climate change resilience into water resource planning and project design and related economic development planning.

2.3.3 Assign a higher priority to climate resilient programs and projects when administering Federal grant programs relating to water supply, wastewater, and water resources projects, including EPA's Clean Water and Drinking Water State and Tribal Revolving Funds, as allowable under applicable statutory frameworks.

Recycled water is used to irrigate landscaping in Pittsburg, CA. Photo Credit: *Florence Low, California Department of Water Resources.*

Climate-Smart Water Use in Los Angeles, California

Los Angeles is preparing to construct the world's largest advanced groundwater treatment plant in order to recoup the significant loss of its groundwater resources due to contamination, to enable the City to augment its local groundwater supplies through efforts to dramatically increase storm water and recycled water recharge, and to ensure a reliable and adequate local supply during dry years and in the event of an earthquake. Los Angeles is leveraging public and private resources to capture, infiltrate, and reuse stormwater by building multi-benefit green projects that also meet runoff water quality standards and provide greening to communities and better quality of life.

Illinois Clean Water Initiative

In July 2014, Governor Quinn signed into law an expansion to Illinois' Clean Water Initiative, which for the first time in Illinois history allows units of local government to obtain low-interest financing through the Initiative to move forward on capital projects that will remove pollutants from stormwater runoff and other non-point sources. The expansion of eligibility will assist municipalities, sewer districts and stormwater management agencies in Illinois to address capacity and capability of water infrastructure under future climate projections. Further, the $2 billion Clean Water Initiative is greatly expanding the number of affordable loans for communities across the State to invest in resilient water infrastructure.

2.4 Assist transportation officials in better understanding the vulnerabilities and risks to transportation networks and facilities and integrate climate resilience planning and preparedness criteria throughout existing Federal transportation funding programs.

Investments in resilience can reduce costs over the life-cycle of assets in vulnerable locations and also help build sustainable transportation options that reduce greenhouse gas emissions from the transportation sector. However, it can be difficult to justify transportation and infrastructure investments that accommodate future climate impacts when limited resources make it a challenge just to meet present-day demands like keeping the current transportation system in good repair, reducing congestion, and keeping facilities safe. Existing Federal programs can be modified or expanded to encourage inclusion of climate change preparedness and resilience when implemented at the state, regional, territorial, tribal, and local levels:

2.4.1 Develop and disseminate information, analyses, and tools for improving engineering design standards and decision making, so that new and existing transportation networks and facilities can be adapted and made resilient to climate change using the best available science.

2.4.2 Review DOT grants and programs to ensure that State and local governments, Tribes, and territories can access funding for transportation system vulnerability assessments. This includes continuing and expanding the successful Federal Highway Administration (FHWA) Climate Vulnerability Pilot Program.

2.4.3 Amend criteria for DOT's discretionary grant programs to require that recipients address potential climate impacts to any proposed projects. This would include utilizing best available climate data, any available climate vulnerability assessments, applicable local and state climate change plans as they pertain to transportation projects, vulnerability scores, and existing climate adaptation plans or strategies.

2.4.4 Transportation project funds should allow maximum flexibility in the eligibility of climate preparedness and resilience elements so that decision-makers can allocate funds most efficiently to improve public safety and reduce risk balanced against other project factors.

2.4.5 The FHWA should maximize the use of Emergency Relief Program funding to build climate resilience (betterments) into storm-damaged infrastructure, in consultation with state, tribal, territorial, and local jurisdictions and communities.

2.4.6 Building on parameters laid out for the 2014 Transportation Investment Generating Economic Recovery (TIGER) program, specifically and consistently adjust grant criteria and guidelines for TIGER and other DOT grant programs to favor transportation projects that will improve climate resilience.[20]

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[20] "Notice of Funding Availability for the Department of Transportation's National Infrastructure Investments under the Consolidated Appropriations Act, 2014" *U.S. Department of Transportation*, DOT-OST-2014-XXXX. Federal Register, 79(41). 25 February 2014. http://www.dot.gov/sites/dot.gov/files/docs/TIGER%202014%20NOFA_FINAL.pdf

Climate and Transportation Planning in Philadelphia

The Federal Transit Administration's (FTA) Climate Change Adaptation Assessment Pilot Program funded seven projects across the country to advance the state of practice for adapting transit systems to the impacts of climate change.[21] In Philadelphia, several partners came together to conduct a vulnerability and risk assessment of the Southeastern Pennsylvania Transportation Authority's (SEPTA) Manayunk/Norristown regional rail line. This line closely parallels the Schuylkill River, which has experienced 10 of its highest 18 crests in recorded history since 2003, resulting in numerous delays and damage. The Pilot Program built capacity and facilitated the beginning of SEPTA's climate planning work, ultimately positioning SEPTA for a competitive award of $86 million in subsequent Federal funding through FTA's Emergency Relief Program. SEPTA will use the funds to improve disaster preparedness by building an alternate system control center, stabilizing embankments over commuter railroads, and improving flood protection of tracks.

2.5 Support Property Assessed Clean Energy programs.

Building community resilience on regional and national scales will require significant investment in the retrofit of public and private infrastructure. Residential and commercial properties will require improved weatherization to increase energy efficiency and address the potential impacts of extreme weather events. As heating and cooling costs soar in response to changing temperature extremes, energy efficiency retrofits and investments in renewable energy will help reduce energy bills, increase diversification of power sources, and advance distributed energy distribution infrastructure, adding redundancy to power systems. These benefits advance community resilience by freeing-up funds for additional investments and decreasing community vulnerability to economic and public health risks that accompany power loss in the face of natural hazards. Barriers to wide-scale retrofit of existing private properties include limited access to and incentives for long-term financing to cover project costs. Property Assessed Clean Energy (PACE) provides a means of financing energy efficiency upgrades, renewable energy installations, and weatherization improvements on residential and commercial properties through a voluntary property assessment. PACE also offers co-benefits such as spurring local investment and expanding economic opportunities in the green energy sector.

Actions to advance this recommendation include:

2.5.1 Reform policies preventing Freddie Mac and Fannie Mae from purchasing mortgages for properties with PACE loans.

2.5.2 Support the development of PACE programs that address locally relevant energy efficiency programs, renewable energy installations, and weatherization improvements.

2.6 Support development of a clean and resilient energy grid.

The country's energy grid is vulnerable to extreme weather that can cause prolonged and widespread power outages. Such extremes are likely to increase as global temperatures continue to rise. Higher temperatures also decrease power plant efficiencies during periods when electricity demand is the highest, placing additional stresses on the electricity system. In order to develop more robust, resilient energy infrastructure that is prepared for climate impacts, there is a need for policy and regulatory certainty that encourages upgrading electric infrastructure to enhance its resilience. These upgrades include not only hardening existing transmission and distribution systems, but also expanding them to include currently disconnected communities and incorporating efficient, renewable and low-carbon

[21] See "Announcements of Project Selections: Transit Climate Change Adaptation Assessment Pilots," http://www.fta.dot.gov/sitemap_14228.html

technology, resilient microgrids that can function as back-up systems, and distributed generation. Improving the resilience of electricity distribution and transmission line networks can reduce the number and length of outages and the cost to local and state economies.

Electrical grid failure. Photo Credit: *NCA, Iwan Baan/Getty Images.*

Actions to advance this recommendation include:

2.6.1 Incentivize investments in resilient, distributed microgrids and renewable energy microgrids through the Commerce Department's Comprehensive Economic Development Strategies and other Federal programs as appropriate.

2.6.2 Encourage the deployment of a microgrid framework to develop robust distributed generation systems using a variety of networked clean energy technologies that can also provide backup power as needed. Providing and promoting technical assistance for developing microgrids with combined heat and power can help ensure that the energy demands of a community or facility are met.[22]

2.6.3 Promote resilient microgrid development by providing technical assistance through the Department of Energy (DOE) to states and electric distribution utilities that seek to make utility hardening improvements; by encouraging the Federal Energy Regulatory Commission (FERC) to open a docket designed to incentivize and reduce barriers to resilient microgrid development; and by providing loan guarantees for resilient microgrid deployment through the DOE Loan Programs Office.

2.6.4 Expand energy partnerships with Tribes to include incentives for siting on or near tribal lands and Federal promotion of grid accessibility for Tribes. Such partnerships should include opportunities for revenue sharing and/or ownership where appropriate.

2.7 Finalize guidelines for consideration of climate impacts and greenhouse gas emissions in National Environmental Policy Act evaluations of proposed Federal actions.

In accordance with the National Environmental Policy Act (NEPA), Federal agencies are responsible for analyzing the environmental effects of proposed Federal actions. In 2010, the CEQ released draft guidance to Federal agencies on consideration of effects of climate change and greenhouse gas emissions in their evaluation of proposals. The guidance affirms that greenhouse gas emissions and climate change impacts should be considered in developing NEPA reviews, and asked for comment on whether and how to address those effects for land management proposals. This guidance has yet to be finalized. Meanwhile, projects and investments are being advanced without adequate and coordinated consideration of the project design or alternatives relative to climate impacts and greenhouse gas emissions, a direction that generates unacceptable public health, safety, and financial risks for communities. The Administration should finalize guidance for considering climate impacts and greenhouse gas emissions in NEPA evaluations of proposed Federal actions.

[22] Executive Order 13624 on Accelerating Investment in Industrial Energy Efficiency may offer a vehicle for advancing this action. See http://www.whitehouse.gov/the-press-office/2012/08/30/executive-order-accelerating-investment-industrial-energy-efficiency.

Theme 3: Ensuring Resilience of Natural Resources

The way lands and waters are managed and sustained has significant implications for the Nation's ability to cope with the impacts of a changing climate. Protecting and conserving natural systems, including agricultural lands, rural and urban forests, grasslands, lakes, oceans, coral reefs, and other natural habitats, can help protect critical livelihoods, reduce human vulnerabilities and enhance community resilience in a cost-effective manner.

The Administration's Climate and Natural Resources Priority Agenda[23] (Agenda), released in October 2014, identified a suite of actions the Federal Government will take to enhance the resilience of the Nation's natural resources to the impacts of climate change. The Agenda reflects a Federal commitment to ensure the resilience of natural resources on which communities across the country depend by advancing climate-smart conservation practices and optimizing carbon storage and sequestration in land and water resource management. The recommendations below highlight opportunities to build on this commitment to ensure the resilience of the Nation's natural resources.

Big Cottonwood Canyon in the Central Wasatch Mountain Watershed, Utah. The watershed is a critical water supply to the Salt Lake Valley. Photo Credit: *Patrick Nelson.*

[23] See "Priority Agenda: Enhancing the Climate Resilience of America's Natural Resources," by the Council on Climate Preparedness and Resilience. http://www.whitehouse.gov/sites/default/files/docs/enhancing_climate_resilience_of_americas_natural_resources.pdf

3.1 Restore and conserve ecosystems and lands to build resilience in a changing climate. Conservation of natural and working lands can help communities mitigate and prepare for climate change by supplying clean water, local food supplies, and other critical services; serving as buffers against flood impacts and storm surge; storing water and recharging aquifers; helping to moderate local temperatures; and providing vital habitat for native and migratory wildlife. These benefits—and community resilience—can be better realized with investments in ecosystem conservation and restoration.

Actions to advance this recommendation include:

3.1.1 Target lands for conservation that provide climate resilience benefits. The goals, guidance, and funding criteria of Federal conservation and land acquisition programs should incentivize the restoration and protection of land that contributes to long-term climate resilience and the provision of important ecosystem services.[24] Federal policy should also incentivize private conservation and reduced conversion of working lands to urban lands. Federally-funded land acquisitions in hazard-prone areas should be maintained as open space or other non-conflicting use (such as recreational areas), and not reoccupied.

3.1.2 Federal agencies including DOI, USDA, EPA, USACE, and NOAA should foster landscape-scale and regional conservation by identifying and developing landscape-level and regional partnerships to support resilience. Resources should be coordinated and leveraged on an interagency basis—for example, USDA Climate Hubs, DOI Climate Science Centers, Landscape Conservation Cooperatives, and other Federal climate science efforts—to advance collaborative research and conservation on a scale more effective for supporting resilience.

3.1.3 USDA and DOI should require climate resilience planning for natural resources. State and regional planning processes such as State Wildlife Action Plans and State Forest Action Plans should be required to consider impacts of climate change and address resilience priorities.

3.1.4 USDA, DOI, FEMA, and other agencies can reduce human and ecosystem vulnerability to wildfires by prioritizing pre-fire forest fuel thinning and post-fire forest restoration to address forest health needs, especially in the most vulnerable watersheds. Wildfire risks to adjacent communities can be reduced by providing resources and assistance for fire-safe homes and communities.

A home destroyed by wildfire in Okanogan County, Washington. Photo credit: *Washington Governor's Office.*

[24] Opportunities for implementation include the Land and Water Conservation Fund (i.e. Forest Legacy), Natural Resources Conservation Service Programs (e.g. Agricultural Conservation Easement Program, Wildlife Habitat Incentive Program, Environmental Quality Incentives Program), Cooperative Forestry Assistance programs and grants, NOAA's Coastal and Estuarine Land Conservation Program, and other programs that seek to protect working and natural lands through fee acquisition, easements, grants, land-owner agreements, and contracts.

3.1.5 Minimize the decline of marine life, wildlife, pollinators, and plants vulnerable to climate change by supporting full and robust implementation of the National Fish, Wildlife and Plants Adaptation Strategy and enhanced interagency coordination.[25]

Knoxville's "Urban Wilderness"

Over the last four years, the City of Knoxville, Tennessee has worked with local partners to establish an outdoor recreation destination on more than 1,000 acres of forested land along Knoxville's downtown river-front. This "urban wilderness" includes ten parks, more than forty miles of recreational trails, a nature education center, a wildlife management area, four Civil War sites, incredible views, and unparalleled natural features. In addition to providing recreation and aesthetic assets to the community, Knoxville's conservation efforts also protect the ecosystem services provided by forests and natural open spaces, such as clean water, water retention, wildlife habitat, soil stabilization, and urban cooling. Given East Tennessee's Appalachian topography, these natural resources help increase local resilience to strong rainfall and heat events, which are expected to become more intense and frequent as the climate changes.

"Knoxville's efforts to conserve natural open space in its urban core achieve a variety of recreation and conservation benefits. Federal support for communities to conserve and restore local ecosystems will boost resilience while also improving quality of life for residents."

- **Mayor Madeline Rogero, City of Knoxville, Tennessee**

3.2 Combat the spread of invasive species, pests, and diseases.

A changing climate can create conditions that benefit invasive pests, animals, plants, pathogens, and diseases that degrade agricultural, forest, and fishery productivity and quality; accelerate the decline of native plants and animals; weaken ecosystem resilience; and adversely impact human health and the economy. The Federal Government should work closely with State and local governments, Tribes, and territorial jurisdictions to strengthen biosecurity and improve control of invasive species, pests, and disease as a means to prepare for and adapt to climate change by improving coordination; providing tools and funding for prevention, early detection and rapid response, control and eradication; and demonstrating leadership in enforcement of related laws and quarantines.[26]

Actions to advance this recommendation include:

3.2.1 Assess the need for stricter regulations, inspection, and enforcement for importation of plants and animals to prevent new introductions of invasive species.

3.2.2 Integrate climate resilience and adaptation planning into invasive species programs and partnerships, including the National Invasive Species Council, the Invasive Species Advisory Council, the Great Lakes Restoration Initiative, and similar regional efforts, and integrated pest management programs.

3.2.3 Increase regional monitoring of the spread of invasive species, analysis of pests and potential threats, eradication methods and control methods (such as biocontrol technology) through enhanced research, identification, interagency coordination, and education efforts.

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[25] See "National Fish Wildlife, Plants Climate Adaptation Strategy," http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Final.pdf

[26] See the *Climate and Natural Resources Priority Agenda* for more information on Federal commitments that correlate with this recommendation. http://www.whitehouse.gov/sites/default/files/docs/enhancing_climate_resilience_of_americas_natural_resources.pdf

Hawaii's Interagency Invasive Species Council

"The council works to break down silos within government for an integrated, cross-sector approach to align shared priorities and identify opportunities for collaboration. HISC appreciates Federal agency participation in the council and strongly supports State-Federal joint inspection facilities at ports as an effective biosecurity partnership. The National Invasive Species Council has been a key partner with ongoing communication and coordination between local, State, regional and Federal governments."

- **Governor Neil Abercrombie, State of Hawaii**

3.3 Support resilience planning for ocean and coastal ecosystems.[27]

Ocean acidification, changes in salinity, and increasing water temperatures along coasts and within estuarine systems are growing concerns among fisheries and resource managers. Climate-related ocean acidification and hypoxia (a lack of oxygen in the water) are also serious threats to ocean health, especially for corals and coral reefs and the communities that depend on ocean and coastal resources. Of particular concern to remote communities, especially islands and Alaska Natives villages, is the ongoing impact of coastal erosion and thawing of permafrost that may be caused or made worse by climate change. Federal resources to proactively address erosion and permafrost issues are very limited, yet are critically important to local communities and island nations. As the extent and severity of ocean and coastal climate change impacts increases, solutions must include collaboration and commitment from all levels of government, nongovernmental organizations, and citizens to protect resources and the populations that call these areas home. Federal agencies should work more closely with coastal, island, and Great Lakes States, territories, Tribes and other jurisdictions to research, model, and monitor impacts of ocean acidification, sea level rise, and increasing water temperatures on coastal and marine ecosystems, including migratory bird and fish habitats. In doing so, State and local governments, Tribes, and territories, along with university and international partners, should coordinate to advance solutions that strategically target available resources and assistance to advance adaptation and resilience.

Bleaching of coral colonies in Pago Bay, Guam. Photo Credit: *D. Burdick/ University of Guam Marine Lab.*

[27] See related recommendations on coastal infrastructure (2.1).

3.4 Promote integrated watershed management and planning to protect water quality and quantity. [28]
Longer periods of more intense drought, increased evaporation due to higher temperatures, degradation of forests and landscapes, variable precipitation patterns, and changes in mountain snowpack may impact the quality and quantity of water for drinking and for agricultural and ecological needs. Increases in extreme precipitation events also create serious concerns for water quality, as much of the Nation's infrastructure is not designed to accommodate short-duration, high-intensity rain events. Federal policies and programs should encourage and incentivize integrated, multi-jurisdictional, watershed-based approaches to manage stormwater, reduce flood risk, and protect water quality and quantity. Such policies and programs should leverage resources to realize the multiple benefits of helping communities become more sustainable and resilient.

Actions to advance this recommendation include:

3.4.1 Federal agencies including EPA, NOAA, and DOI, should work with State and local governments, Tribes, and territories to support the development of comprehensive regional data-provisioning and modeling initiatives to provide decision-makers with adequate information to plan for and adapt to climate change impacts on water quality and quantity.

3.4.2 EPA and other Federal agencies should improve stormwater and water quality BMPs, including green infrastructure practices, to reflect enhanced understanding of climate impacts on water quality, and help institutionalize them into stormwater and water quality management programs at all levels of government.

3.4.3 Federal agencies including EPA, USACE, DOI, and USDA should work together to develop a national, integrated water strategy that focuses on interagency support for watershed restoration, groundwater partnerships, water (storm and waste) reclamation and reuse, and water conservation. Establish regional interagency water security partnerships that include state, local, and tribal representatives.

Hawaii's Watershed Partnerships construct fences in critical natural areas to protect natural resources and ecosystem services from the impacts of invasive animals. Photo Credit: *Emma Yuen, Hawaii Department of Land and Natural Resources.*

[28] See related recommendations on green and natural infrastructure (2.2).

"The plan will provide water and habitat managers with the tools they need to cope with the anticipated detrimental effects of climate change on snowpack and streamflows. Basin stakeholders… chose to set aside their personal interests and work together to formulate a comprehensive set of solutions that benefit the basin as a whole."

- **Governor Jay Inslee, State of Washington**

Yakima River Basin Integrated Water Resource Management Plan, Washington State

The Yakima Basin Integrated Plan is a collaborative plan to build resilience for the river basin as climate change strains the water resources on which its farms, families and fish all depend. Having faced water challenges for decades—including five drought years in the last twenty—and with mountain snowpack expected to decline significantly, the people of the basin face grave threats to their livelihoods. Recognizing this, local, county, and tribal governments, the conservation community, irrigation districts and others joined together with State and Federal agencies on a comprehensive plan to protect and enhance habitat and improve water supply for irrigation, municipal and domestic uses.

3.5 Enhance the scientific understanding of climate impacts on natural resources and provide technical assistance to help communities reduce adverse climate impacts.

Accurate, up-to-date information is needed to manage forest, fishery, and working land health, ensure long-term carbon benefits, assess the conditions and trends of forest carbon stocks, address climate-driven stressors on forests, fisheries and agriculture, and fully understand the interactions with other natural cycles and systems. Existing inventory efforts, research, and applied science partnerships to understand and address threats such as fire, invasive outbreaks, and climate change should be supported and developed in ways that provide landowners, natural resource managers, and policy makers with the information they need to make sound decisions.

Actions to advance this recommendation include:

3.5.1 USDA and other Federal land managers should support research programs that monitor how climate is affecting agricultural and natural resources in the near- and long- term.

3.5.2 Federal conservation programs should test, disseminate, and incentivize the use of BMPs for managing climate impacts and for promoting ecosystem resilience of agricultural, forest and rangeland, and freshwater, and marine systems. Federal, state, local, tribal, and territorial resource managers should seek opportunities to collaborate on research and management strategies, especially where land and other resources are managed within the same watersheds.

3.5.3 USDA's Forest Service programs, such as the National Forest System and the State and Private Forestry Program, should develop BMPs for use in developing state forest adaptation goals and strategies in Forest Action Plans and consider ways to enhance urban forest canopies.

Theme 4: Preserving Human Health & Supporting Resilient Populations

A comprehensive approach to climate preparedness and resilience must consider more than adaptation strategies for the built and natural environments; it fundamentally must account for the resilience of people and communities. Communities must have the capabilities and capacity to recognize the impacts of climate change on public health, social networks, and the needs of vulnerable populations—which will bear disproportionate burdens under a changing climate—prepare for those impacts, and develop mechanisms to enhance resilience among residents. The Federal Government has an important role to play in safeguarding critical health needs and removing institutional barriers to climate preparedness. The following recommendations offer ways the Federal Government can support state, local, tribal, and territorial efforts to preserve and enhance the health and social resilience of communities in the face of a changing climate.

Young Vermonters join outpouring of support for Irene flood survivors (2011). Photo Credit: *Gordon Miller.*

4.1 Address the needs of vulnerable populations.
Certain populations, especially those that already face economic or health-related challenges, are likely to be disproportionately burdened by climate impacts. These populations may include tribal, Alaska-Native, and island communities, as well as low-income citizens or those with existing health conditions or vulnerabilities (small children, the elderly, those with chronic medical conditions, and individuals with medical disabilities). Vulnerabilities may be heightened by physical location, limits to financial or other resources, lack of access to emergency services, support, health care, or other limitations. To increase the resilience of these populations, decision makers and private sector partners need locally-specific information, tools, and resources to understand and assess climate risks, identify the populations most vulnerable, and develop effective preparedness and resilience strategies.

Actions to advance this recommendation include:

4.1.1 Develop guidance and tools that consider geographic, economic, and social contexts to help identify disproportionately vulnerable populations and those most at risk to the effects of climate change. In addition to Census data, tools should build on existing Federal programs that track public health data, provide information to support the planning and siting of public housing, and provide mapping tools and imagery products that inform environmental and health considerations regarding vulnerable populations.

4.1.2 Federal programs that serve vulnerable populations (e.g. flood insurance, disaster recovery, public health, occupational health, energy assistance, water utility assistance, supplemental nutrition, economic development, senior assistance programs, and housing programs) should evaluate how climate change will impact needs and service delivery and integrate consideration of these impacts in strategic planning and funding allocation.

4.2 Improve capacity to protect public health.
Climate change will exacerbate existing public health risks and contribute to new threats, including shifts in the emergence and distribution of some diseases. The public health community needs support to prepare for worsening and emerging risks to public health from the impacts of climate change. Specific actions to advance this recommendation include:

4.2.1 Expand and build on the Centers for Disease Control and Prevention (CDC) Climate-Ready States and Cities Initiative, which currently provides tools and guidance to 16 states and two large cities' health departments through the Building Resilience Against Climate Effects (BRACE) program. BRACE provides a pathway for health departments to build capacity and incorporate climate resilience planning into their programs. Mechanisms for grantees to share their experiences, best practices and model programs with non-grantees, including all local governments, should be strengthened.

4.2.2 Encourage recipients of CDC's Public Health Emergency Preparedness (PHEP) cooperative agreement funding to consider climate change impacts when developing their PHEP-required hazard and vulnerability assessments and develop mitigation strategies, as appropriate.

4.2.3 Support the development and enhancement of climate-sensitive health tracking and surveillance tools, including mechanisms to track disease vectors, and support research into low-toxicity pesticides to limit risks from these vectors and other strategies to limit disease spread caused or exacerbated by climate change.

4.2.4 Improve awareness of mental health needs and services in preparedness planning and disaster response and recovery, including extreme weather events training for mental health professionals relating to climate-related risk factors and stressors. All-hazard emergency preparedness and response funding should explicitly address stress, anxiety, depression or other potential behavioral health impacts associated with climate-related disasters and other long-term impacts of climate change.

4.3 Assist communities in building food system security.
Climate-related food shortages and associated changes in food production patterns can result in price spikes, reduced food quality, and decreased supply due to impacts on production, transportation, and storage. This is especially important in remote and subsistence communities, but also in urban "food deserts."[29] Risks to the agricultural sector directly impact farm worker communities, which has a ripple effect on local, state, tribal, and Federal assistance programs and community cohesiveness. The Federal Government should assist communities in building food system security by protecting and conserving natural resources and helping farmers, fishermen, and other stakeholders understand climate impacts and preparedness strategies, while providing resources and incentives to support climate-smart local, small-scale, and healthy food production and distribution in rural and urban areas.

Actions to advance this recommendation include:

4.3.1 USDA and other relevant agencies, such as NOAA, the Department of Health and Human Services (HHS), EPA, and DOI/Bureau of Indian Affairs, should support research to build increased understanding of climate change-related risks to both public and private sector aspects of food supply chains, including subsistence-based food systems and agricultural workers and communities. This should include encouraging regional marine and terrestrial food-shed and water resource vulnerability maps to visualize food sources and pathways to market in a particular area.

4.3.2 USDA should conduct a comprehensive risk assessment of the direct and indirect impacts of climate change on supplemental food and nutrition programs and develop strategic climate preparedness and resilience plans for these programs.

4.3.3 Support subsistence activities central to the economic and food security of tribal, Alaska-Native, territorial, indigenous island, and other communities. These communities and their representative jurisdictions must be fully integrated into resource governance decisions that affect their food sources, including the Federal Subsistence Board, fishery management councils, and co-management organizations.

4.4 Improve disaster preparedness for communities most at-risk.
Every community located in a hazardous area—whether on a low-lying coast or on a fire-prone hillside—should prepare for potential disasters, including those that may be new or getting worse under a changing climate. This includes disaster preparedness, response, and recovery planning. The Federal Government should provide support to these communities and regions to create integrated risk management plans for evacuation, sheltering, and meeting medical, nutrition, and other humanitarian needs during a disaster.

Decentralized Supply Distribution Centers
Houston, Texas

With support from DOE, the City of Houston has created a network of mobile community support and disaster response energy stations that can operate off the grid and provide basic needs to the community. The solar generators/mobile offices, with battery back-up, are designed for emergency relief efforts after hurricanes or cooling centers during times of extreme heat. Support provided by these units includes water and food, charging stations for phones and medical equipment, and case work assistance. When not being used in an emergency, they are used year-round for services, outdoor classrooms or to educate the public and bring awareness to solar projects.

[29] Food deserts are urban neighborhoods and rural towns without ready access to fresh, healthy, and affordable food. See http://apps.ams.usda.gov/fooddeserts/foodDeserts.aspx

Actions to advance this recommendation include:

4.4.1 Provide or enhance access to pre-disaster training on Federal response and recovery programs for elected officials, community and tribal leaders, agency staff, and first responders in high-risk areas, in order to help communities mobilize for recovery efficiently and effectively.

4.4.2 Build capacity for sheltering and basic supply distribution with guidance and technical support to help communities prepare for widespread distribution of food and other basic supplies, and identify and prepare shelters that can be used during and after extreme weather events without interfering with key community services.

4.4.3 Remove regulatory and technical barriers in order to help communities deploy back up and grid-tied renewable distributed energy generation. Back up energy generation should include solar/battery storage, wind, combined heat and power, and/or extend the life and stability of fuel-based generators, and should prioritize key facilities for first responders and evacuation to ensure basic load priorities (e.g., fueling of emergency vehicles, lighting, heating and cooling, phone charging, and refrigeration of medicine).

4.4.4 Federal agencies should develop health-sensitive extreme weather event warning systems that are sensitive to changes in climate and enhance response activities for at-risk populations.

4.5 Explore Federal role in addressing climate change-related displacement, needs of affected communities, and institutional barriers to community relocation.

Urgent and long-term climate change impacts, including drought, sea level rise, coastal erosion, and water degradation are already affecting and will continue to affect the habitability of places where people live and work. As a result, displacement and migration of populations can be expected in every region of the country and in U.S. affiliated jurisdictions.

The Federal Government has an opportunity to provide international leadership by establishing an institutional framework for responding to the complex challenges associated with climate-related displacement. This framework will help Federal agencies and partners provide coordinated, critical support to affected communities across the United States. State, local, tribal, and territorial entities should be consulted and involved in the development of the framework.

> *"In Alaska, the communities of Shishmaref, Newtok and Kivalina have decided that the relocation of their entire community offers the only viable long-term strategy to protect their communities and residents. Accelerating rates of erosion, caused by the combination of repeated extreme weather events, thawing permafrost and decreased arctic sea ice, are causing the land that makes up these communities to permanently disappear. Each community has worked for more than a decade to facilitate relocation. Institutional barriers and the lack of a designated coordinating Federal agency has hampered the local efforts to move their communities to a safe location. Federal and state agencies need to work together with local residents to overcome the barriers and relocate the residents to safety."*
>
> - **Mayor Reggie Joule, Northwest Arctic Borough**

Theme 5: Supporting Climate-Smart Hazard Mitigation and Disaster Preparedness and Recovery

Scientific findings and recent experience alike demonstrate that certain types of extreme events will become more frequent or severe in a changing climate, with potential impacts to the economy and communities including high recovery costs for repairing and rebuilding infrastructure and buildings. The following recommendations offer ways the Federal Government can further support regional, state, local, tribal, and territorial efforts to prepare for disasters, recover in a way that enhances future resilience, and prevent and mitigate hazards wherever possible.

Erosion of Guam's coast, Talofofo Bay, Guam. Photo Credit: *D. Burdick/Bureau of Statistics and Plans.*

Fort Collins' Path to Resilience

Fort Collins experienced a devastating flood in 1997 that caused loss of life and property. Following that incident, the City implemented a variety of management strategies to mitigate the impacts of floods on life, health, and property in floodplain areas, including floodplain regulations, open space preservation, acquisition of at-risk structures, stormwater capital projects, public education, and flood early warning systems. The Fort Collins Floodplain Management Program is now ranked as one of the top programs nationwide under the FEMA Community Rating System. In September, 2013 another catastrophic flooding event occurred in northern Colorado, causing millions of dollars in property and infrastructure damage. As a result of investments in resilience and mitigation planning, Fort Collins experienced minimal impact, and instead was able to assist neighboring communities in their recovery efforts.

"Community investments in resilience pay off in protecting human life, minimizing loss and lowering recovery costs. Federal agencies should incentivize local policy implementation and investments in hazard-prone areas to protect life and property."

- **Mayor Karen Weitkunat, Fort Collins, Colorado**

5.1 Build a stronger culture of partnership and service to communities impacted by disaster.
In the wake of a disaster, leaders in state and local government, tribes, and territories often find themselves needing to master the differing rules and procedures of myriad Federal funding programs while working rapidly to establish effective, coordinated response across multiple levels of government, special districts, and private sector and other nongovernmental organizations. Federal officials can support swift, resilient recovery by coordinating Federal resources and facilitating effective and efficient access to those resources, reflected through clear and consistent guidance, sustained technical support, and effective partnership efforts.

Actions to advance this recommendation include:

5.1.1 FEMA should convene and manage multi-agency Federal teams to work with and provide more coordinated assistance to state, local, tribal, and territorial leaders in implementing a comprehensive approach to recovery and utilizing a full range of funding sources from across Federal agencies and programs. FEMA's Federal Coordinating Officers and recovery field staff should be trained in the range of applicable Federal programs as well as in effective team building, problem solving and management so that they can coordinate broad and effective Federal recovery partnerships. These teams should include state, local, and tribal participants to incorporate local knowledge and leverage existing partnerships.

5.1.2 Minimize staff transitions in Federal field teams deployed to disaster-stricken areas and ensure information transfer to minimize disruption and inconsistent practices when staff transitions occur. Utilize a clear and consistent set of guidelines and criteria for making and communicating decisions on funding eligibility and requirements.

"In my time as Mayor, Des Moines has experienced an unprecedented number of 100 and 500 year flood events. Our responsibility as a City is to ensure the safety of all our citizens and their property. Sometimes that process requires strategic buyouts of properties that fall within the floodplain. For this to work effectively, local, state, and federal partners must work closely together and interagency coordination must be a priority in order to avoid conflicting direction from multiple authorities that negatively impact residents."

- ***Mayor Frank Cownie, Des Moines, Iowa***

5.1.3 Foster productive and efficient recovery partnerships by providing joint pre-disaster training on rebuilding with resilience for Federal staff, state agencies, and tribal, territorial, and local leaders in vulnerable areas, including on resources, requirements, and opportunities. Create and publicize web resources providing consolidated information from multiple agencies about funding, technical resources, and best practices.

5.1.4 Improve FEMA's Disaster Assistance Programs by providing clear and consistent thresholds for eligibility and procedures for applicants, procedures for damage assessments, and alignment with other Federal disaster relief programs.

Residents creating sandbags in Des Moines, Iowa, 2010.
Photo Credit: *The City of Des Moines' Public Works Department.*

5.2 Remove barriers to rebuilding for future climate resilience.

Rebuilding damaged areas and infrastructure after a disaster is an investment that should be informed by the best available science on climate risks. Federal recovery programs should consistently support repair and rebuilding projects that also mitigate future climate hazards. Administrative obstacles to funding in this way should be eliminated. Federal studies have demonstrated that every dollar invested in mitigating future disaster risks avoids more than four dollars in future recovery costs,[30] demonstrating the economic value of investing Federal recovery dollars in climate-smart projects.

Actions to advance this recommendation include:

5.2.1 Modify disaster recovery programs to encourage and prioritize projects that are sized and designed to withstand future climate impacts and that are located outside areas vulnerable under current or foreseeable conditions.[31]

5.2.2 Coordinate eligibility and grant documentation requirements for similar types of projects across different agencies' recovery funding programs to reduce red tape, speed project implementation, and lessen administrative costs. Additionally, help communities finance resilient recovery investments with higher upfront costs by allowing jurisdictions to combine funds from different Federal programs administered by different agencies.

5.2.3 Support small, remote, and rural communities, as well as tribal areas, territories, and island communities, that lack the capacity to identify and execute resilient recovery investments by providing enhanced technical assistance, removing barriers to hiring grant specialists and project coordinators, and lowering or removing grant match requirements where they present a significant barrier.

[30] Rose, Adam, et al. "Benefit-Cost Analysis of FEMA Hazard Mitigation Grants." *Natural Hazards Review* 8.4 (2007): 97-111. University of Southern California, 1 Nov. 2007. http://research.create.usc.edu/cgi/viewcontent.cgi?article=1014&context=published_papers

[31] Relevant programs include FEMA's Individual Assistance, Public Assistance, and Hazard Mitigation Assistance, HUD Community Development Block Grant – Disaster Recovery, and Small Business Administration (SBA) disaster assistance programs.

Rebuilding a Stronger Vermont after Hurricane Irene

"Vermont was committed to building back stronger after Irene ravaged our State in 2011 – destroying over 500 miles of roadway, and flooding thousands of homes, businesses and farms. We built partnerships with FEMA and FHWA focused on removing the barriers to resilient rebuilding plans. We insisted on relocating our state hospital out of a flood plain, purchasing properties to remove homes and businesses from future harm, and rebuilding larger culverts and bridges to protect our communities from future storms. Federal agencies must build stronger partnerships through recovery and work together to find common sense solutions that enable communities to build for the future."

- **Governor Peter Shumlin, State of Vermont**

Vermont learned from Irene and other floods that erosion damage from river flooding puts communities, infrastructure, and the economy at risk. Vermont has developed a science-based methodology for mapping erosion hazard zones adjacent to rivers that is helping to identify vulnerabilities to future flooding. The State is improving management of river corridors and floodplains and is working with communities to assess risks and take action to reduce future hazards.[32]

5.3 Incentivize and fund Community Resilience Plans with a holistic approach to preparedness and recovery.

After major disasters, communities dealing with extensive damage have a rare opportunity to significantly enhance their readiness for future climate-related risks. The Federal Government should encourage and fund a comprehensive approach to planning and implementing forward-looking investments that can significantly reduce future risk. This is especially important in urban areas, where recovery programs are designed to fund a series of individual projects that may not address more systemic risks facing entire neighborhoods or commercial areas (such as inadequate stormwater management or lack of natural infrastructure for buffering storms).

Actions to advance this recommendation include:

5.3.1 Federal recovery programs should permit funding for projects outside of the immediately damaged area if those investments would have significant and demonstrable benefits for risk reduction under present or anticipated conditions.

5.3.2 Coordinate across Federal agencies to accelerate the pre-disaster planning and post-disaster execution of buyouts in areas prone to coastal or riverine flooding or wildfire under current or anticipated conditions.

"After Superstorm Sandy, the City of Hoboken began developing plans to make the city more resilient to flooding. Representatives from FEMA explained that the City could receive funding to flood-protect fire stations, a community center, and other municipal facilities, but not for measures that would provide protection to the entire city. During future flood events, this approach would result in having "islands of protection." Even if a firehouse were protected from flooding, it would be inaccessible and unusable. Funding policies should be structured to allow for mitigation measures that can protect larger areas, including entire communities."

- **Mayor Dawn Zimmer, Hoboken, New Jersey**

[32] See http://accd.vermont.gov/strong_communities/opportunities/planning/resiliency/VERI and http://floodready.vermont.gov/

5.3.3 Identify, evaluate, and pilot innovative financing strategies—such as special districts focused on financing resilience measures, bonds, and public-private partnerships—that could leverage reductions in post-project insurance premiums or other private sector funding to raise capital for investments to increase resilience

5.4 Modernize data collection, analysis, and mapping based on current and predicted climate impacts to help improve local capacity for effective hazard mitigation planning.

Many communities have not yet calculated and evaluated risks associated with climate change for infrastructure, public health and safety, or built and natural environments. Insufficient or inaccurate data stymie hazard evaluation and sound mitigation plan development. In particular, out-of-date or inaccurate flood hazard maps impede the efforts of communities to understand and assess vulnerability to sea level rise, coastal storm surge, and riverine flooding and to develop policies and projects to reduce risk. Erosion hazards, which are likely to worsen in many parts of the country due to predicted increases in extreme precipitation events, remain largely unmapped. Communities also lack information about changing wildfire risk, drought and other climate-influenced hazards. In response to these challenges, initiatives at all levels of government are underway to leverage private and other nonfederal sources of data, to build partnerships to generate and analyze mapping data, and to promote the use of the best-available science in land use decisions. These innovations and partnerships should be supported by Federal agencies. Additionally, Federal investments in mapping and data need to be prioritized to deliver mapping products and other tools that support nonfederal efforts to manage risks in addition to flood, including wildfire, landslide, erosion, and drought.

A home is left standing among debris from Hurricane Ike (2008) in Galveston County, Texas. Floodwaters from Hurricane Ike were as high as eight feet in some areas causing widespread damage across the coast of Texas. Photo Credit: *David J. Phillip-Pool/Getty Images.*

Actions to advance this recommendation include:

5.4.1 Federal agencies such as FEMA, NOAA and United States Geological Survey (USGS) should collaborate with State and local governments, Tribes, territories, universities, private sector, and other nongovernmental organizations to accelerate the development of hazard maps that integrate climate change, ocean acidification and sea level rise projections. Federal, state, tribal, territorial, and local mapping projects should coordinate and share data to avoid redundancy, leverage resources, and prioritize funding.

5.4.2 Provide adequate funding to update NFIP Flood Insurance Rate Maps to reflect expected sea level rise, changes in storm frequency and intensity, shoreline change, and changes in river and localized flooding in order to inform planning, regulate development, and target cost-effective investments for minimizing future flood damage.[33]

[33] The Association of State Floodplain Managers estimated the cost for providing flood maps nationwide at $4.5 to $7.5 billion, a good investment given that the *annual* cost of flood damages in the United States from 2000-2009 was $10 billion. For more information, see: “Flood Mapping for the Nation: A Cost Analysis for the Nation’s Flood Map Inventory,” *Association of State Floodplain Managers (ASFPM). 1 March 2013.* http://www.floods.org/ace-files/documentlibrary/2012_NFIP_Reform/Flood_Mapping_for_the_Nation_ASFPM_Report_3-1-2013.pdf

"Guam is in the most active area for typhoons in the world and is in the only basin that can have a hurricane or typhoon any month of the year. Our community has endured super typhoons; lived without power, water, and gas for weeks; recovered from hundreds of millions of dollars in damaged infrastructure; and revitalized our tourism industry. Guam's story demonstrates a community's size is not always a good measure of the vulnerability and risk it faces."

- ***Governor Eddie Calvo, Island of Guam***

5.4.3 FEMA's Risk Mapping, Assessment, and Planning program should map current and projected 500-year floodplains throughout the U.S. in order to reduce risk to critical facilities under the requirements of Executive Order 11988.[34]

5.4.4 Help State and local governments, Tribes, and territories manage disaster risks by building their capacity to monitor and assess hazard risks and providing technical assistance on interpreting hazard maps and using them wisely to support land use management, emergency response, economic recovery efforts, natural resource management, and disaster recovery planning. Scale up community-based training disaster preparedness and planning.

5.4.5 The work of the Technical Mapping Advisory Council should include consideration of strategies for making informed land-use decisions that promote public resilience and safety where detailed maps and information on climate impacts are not yet available.

5.5 Modernize and elevate the importance of hazard mitigation programs.

The Hazard Mitigation Grant Program (HMGP) and Pre-Disaster Mitigation Grant Program have been critical sources of hazard mitigation funding. Improvements in program administration would increase their flexibility and breadth for addressing varying mitigation needs across urban, suburban, Tribal, and rural areas. Reducing the average project approval time is an essential step towards a more effective program, as is lengthening performance timeframes beyond two years**.** To avoid time-consuming and costly Federal reviews of every proposed project, the Administration should consider making the hazard mitigation programs more like a block grant program, similar to HUD's Community Development Block Grants. Pilot programs authorized under the Sandy Recovery Improvement Act have helped states and municipalities and should be made permanent. The newly-announced Mitigation Integration Task Force, intended to identify and invest in projects that will increase resilience, is an important starting point toward a more effective program.

Actions to advance this recommendation include:

5.5.1 Adjust eligibility criteria for Federal programs, including FEMA hazard mitigation programs as well as other Federal disaster recovery programs at HUD, DOT, USACE, EPA, and SBA, to avoid funding activities that may encourage or perpetuate occupation of hazardous or vulnerable areas, such as floodplains, storm-surge zones, and wildland-urban interfaces that are vulnerable to wildfire.

5.5.2 Federal agencies should work together to consolidate requirements for hazard mitigation and encourage integration with land use plans, and streamline plan approval so that urgent mitigation actions are not delayed post-disaster. Grants and technical assistance should also be provided to support risk communication targeting at-risk property owners.

[34] See "Executive Order 11988: Floodplain Management," http://www.archives.gov/federal-register/codification/executive-order/11988.html

5.5.3 Make ecosystem restoration and preservation eligible for the HMGP, the Pre-Disaster Mitigation Program, and the Flood Mitigation Assistance Program, particularly in flood- and drought- prone areas where such natural infrastructure projects can minimize future loss of life and property.

5.5.4 Review eligibility criteria for receipt of hazard mitigation funding and eliminate barriers that prevent tribal and rural communities from accessing this funding.[35]

5.5.5 Adjust eligibility for Federal disaster recovery programs and the FEMA Hazard Mitigation Programs to improve eligibility for measures that address erosion, mudslide, and landslide hazards and that are often not associated with a disaster or not eligible disaster recovery activities.

5.6 Strengthen the National Flood Insurance Program to avoid development that increases exposure and losses to flooding, and eliminate inequities for urban and rural locations.

The National Flood Insurance Program (NFIP) has helped many property owners get back on their feet after losing homes and businesses by providing more direct, rapid, and complete support for disaster recovery, repair, and rebuilding. The minimum standards local governments must adopt to participate in the program should be strengthened to prevent the continued degradation of critical floodplains, wetlands, coastal marshes and dune areas that naturally buffer the impacts of storms and rising sea levels. In low- to mid-risk flood prone areas, insurance rates should be reduced for property owners who rebuild to meet more robust standards and codes. NFIP policies should also be better designed to provide equitable coverage across all types of development and housing in rural, suburban, and urban areas.

Actions to advance this recommendation include:

5.6.1 To address the fact that NFIP insurance policies are not well designed for densely populated urban areas, FEMA should conduct a study to identify solutions to address challenges in NFIP administration in urban areas including addressing properties with basements, differentiating among occupants in multi-family and high-rise housing based on their elevation, addressing common areas of condominiums, and reviewing thresholds for substantial damage determinations.

5.6.2 Develop stronger minimum standard requirements for local governments participating in the NFIP, especially for new development proposed in undeveloped areas where floodplains or coastal shores provide valuable functions for slowing and storing floodwaters and mitigating the risk of flood damage. For example, the NFIP minimum standards for these areas could be founded on an approach that minimizes risks for existing development, avoids adverse impacts for floodplains and coastal shores, and discourages development that worsens flood and erosion risks or produces other adverse impacts upstream, downstream, or on adjacent properties.[36]

5.6.3 Revise FEMA's Community Rating System to award more points when communities adopt comprehensive, community-wide approaches to increase climate resilience and manage risk to reduce the costs of climate impacts and disasters (e.g. with strong building codes).

5.6.4 Provide technical assistance to help communities participate in the NFIP and develop a less administratively burdensome Community Rating System option for smaller communities.

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[35] "Alaska Native Villages: Limited Progress Has Been Made on Relocating Villages Threatened by Flooding and Erosion" *U.S. Government Accountability Office*, GAO-09-551. June 2009. http://www.gao.gov/new.items/d09551.pdf

[36] Sometimes known as "avoidance" or a "no adverse impact" approach.

Theme 6: Understanding and Acting on the Economics of Resilience

Climate change poses significant economic risk to all sectors and communities across the United States.[37] In the face of increasingly frequent and severe storms, flooding, heat waves, and other climate-related disruptions, investments in resilience can reduce future risk and help to protect against severe economic losses and threats to public health and safety. To prepare for these changes, all facets of public, private, and civil society will need to engage in developing new partnerships and strategies to make the best investment decisions possible and reduce the costs of climate impacts that cannot be avoided. The following recommendations offer ways the Federal Government can advance sensible measures to foster more prudent investments in long-term resilience and ensure a vibrant economic future in the face of climate change.

Governor Inslee visits shellfish processing center in Shelton, WA. Ocean acidification has already begun to impact the shellfish industry, an important economic driver in the region. Photo credit: *Washington Governor's Office.*

[37] See for example "Risky Business: The Economic Risks of Climate Change in the United States," June 2014. http://riskybusiness.org/uploads/files/RiskyBusiness_Report_WEB_09_08_14.pdf

6.1 Promote private sector and workforce resilience to reduce economic disruptions associated with the impacts of climate change.

The private sector is responsible for much of the infrastructure of physical plants, supply chains, and retail, commercial, and industrial facilities that local and regional economies rely upon. Federal programs should support regional, state, tribal, territorial, and local efforts to engage the private sector in community resilience and hazard mitigation planning and related projects, including Chambers of Commerce and major employers, as well as architects, engineers, and other designers and the professional organizations that represent them.

> *"Like our Central Coast neighbors and the rest of California, Santa Barbara County is in the middle of a severe drought with our major fresh water lake at only 30% capacity and dropping. Extreme heat events and lack of rainfall have also increased our risk for wildland fires, of which we have had five major incidences over the past decade. In addition, the drought threatens our top industries: agriculture and tourism. A commitment to preparing for a future with climate change will ensure our communities remain secure, stable, and resilient in a future of uncertainty. "*
>
> - **Salud Carbajal, Supervisor, Santa Barbara County, California**

Actions to advance this recommendation include:

6.1.1 Federal efforts to identify community resilience indicators should include metrics of economic resilience, including considerations of supply chains, the work force, and other measures of climate impacts to commercial activity.

6.1.2 Federal policies and programs should encourage participation of business and labor leaders, and representatives from professional organizations and other stakeholders when developing and implementing various regional, state, tribal, territorial, and local community climate-related plans, including Hazard Mitigation Plans, Disaster Recovery Plans, and Climate Adaptation Plans, among others.

6.2 Reward resilient investments and consider the benefits of ecosystem services in cost-benefit analysis.

Adapting to climate impacts will require long-term investments, the benefits of which might not be seen in the short term. There is a longstanding debate among experts and academics on what the appropriate discount rate is for use in projects that have long-term benefits; evidence that discount rates that are lower than conventional rates may be important to consider in order to address difficult economic and ethical questions that arise with long-term investments.[38] Government decision-making processes, particularly related to cost-benefit analyses, can favor short time frames, leading to underinvestment in projects with long-term benefits. These same decision-making processes can fail to adequately consider the long-term and accrued economic, environmental, and societal benefits of climate-resilient investments, resulting in decisions that undervalue or overlook long-term resilience opportunities and lead to greater costs in the long-run. The accounting practices and evaluation criteria used by the Federal government have a significant impact on state, local, and tribal government decision-making, particularly given the large role Federal contributions often play in infrastructure projects. The Federal Government should use this influence to incentivize decision making that accounts for climate related risks and vulnerabilities, and results in longer-term climate resilient strategies and investments.

[38] See for example Portney, P.R., and Weyent, J.P. (Eds.) "Discounting and Intergenerational Equity" RFF Press, 1999.

The following adjustments to policy and practice can further advance this recommendation:

6.2.1 Adjust cost-benefit methodologies across Federal programs to fully value the benefits of front-end investments in resilient planning and design, including in ecosystem services, green infrastructure, and post-disaster rebuilding of damaged buildings and infrastructure with new design standards to consider the future avoided costs associated with responding to climate-related events, such as lost economic productivity, or rebuilding after a disaster. These cost-benefit methodologies should be as uniform as possible across Federal programs.

6.2.2 Allow for flexibility when evaluating projects with benefits that accrue over especially long timeframes, such as those that increase resilience to projected climate impacts. This could include using sensitivity analyses that incorporate lower discount rates, where appropriate, to allow decision makers to make use of that information to more accurately value the return on climate smart investments.

6.2.3 Develop guidance and technical assistance for State and local governments, Tribes, and territories interested in incorporating these practices into their own decision making. Federal agencies might also require the use of some or all of these practices as a condition for receiving Federal grant funds, where appropriate, so long as the cost of applying these requirements are not transferred to tribal and vulnerable communities (creating a barrier to funding self-determined projects or the integration of the guidance into their decision-making).

6.2.4 The Administration should collaborate across Federal missions and programs and with the private sector to develop innovative funding platforms to support resilience investments in retrofits to the built environment that reduce the up-front cost of the retrofit and support long term payback of the investment through on bill financing or other mechanism.

6.3 Safeguard places of national, economic, and historical significance.

Disaster and climate preparedness must become a priority for facilities and infrastructure critical to the smooth functioning of National, regional, state, tribal, territorial, and local economies—whether those are major airports, ports, transportation systems or water and energy production and distribution facilities. A lack of disaster or climate preparedness for these facilities and installations could be catastrophic not only in the immediate community, but also for whole industries or regions served by their operations.

Actions to advance this recommendation include:

6.3.1 Expand funding and technical assistance available to those managing facilities and infrastructure critical to regional economic resilience to help them develop forward-thinking climate and preparedness plans, decision-making tools for rebuilding, strengthening or relocation actions, and develop state-of-the-art tools to enhance preparedness capabilities applicable to their specific climate risks. Plans should be developed with input from and in collaboration among State and local governments, Tribes, and territorial agencies; incorporating local knowledge and priorities; and integrating with existing and evolving climate preparedness planning efforts. Technical assistance should be integrated across Federal agencies to ensure that plans leverage multidisciplinary expertise and accommodate interdependencies at all levels.

6.3.2 Provide guidelines to inform state, territory, tribal and local governmental climate adaptation planning that includes historic and cultural properties and buildings to protect their contribution to tourism, acknowledge and respect their cultural significance, and ensure that quality of life in communities across the country is maintained.

Preparing Facilities with National Economic Significance
Los Angeles and Houston

The Ports of Los Angeles and Houston are two of the largest and most active ports in the world. Together these two ports are responsible for generating over 2.2 million jobs.[39] Wide-spread damage to these ports would result in significant economic loss for the Los Angeles and Houston-Galveston regions, and negatively affect the global supply chain resulting in product shortages and increased costs for consumers and manufacturers. Responsibility for protecting these crucial pieces of national infrastructure should not fall to local governments alone. Measures to increase resilience at these ports, such as micro-grids for electrical power and infrastructure to protect against sea level rise, must be a National priority.

6.4 Collaborate with the insurance industry.
Federal agencies should continue efforts called for in the President's Climate Action Plan to partner with the insurance industry and jointly explore opportunities to:

6.4.1 Adjust pricing structures to incentivize building that anticipates climate trends.
6.4.2 Create incentives through favorable ratings for insurance and bonds for communities that adopt robust resilience standards and practices, including stronger building codes.
6.4.3 Develop policies that require early notification of climate-related natural hazards prior to property transactions.

Representatives of State and local governments, Tribes, and territories should be included in dialogue with the insurance industry to represent the on-the-ground perspective and experience with a diversity of climate risks.

"In Carmel, the first priority is to do what is best for the people. We have made environmental stewardship a top priority, creating jobs and improving the quality of life in our community. It's clear that the poles are warming and we need to be prepared to deal with increases in severe storms, flooding, and extreme heat events we are likely to see in Indiana under a changed climate. Sensible Federal policies and programs will help cities and communities like Carmel become more resilient to these impacts."

- **Mayor Jim Brainard, Carmel, Indiana**

[39] See http://www.portofla.org/about/facts.asp and http://www.portofhouston.com/about-us/economic-impact/

Theme 7: Building Capacity for Resilience

In order to adequately plan for climate impacts and make smart investments in resilience, communities must first have the capacity to recognize, understand, and assess relevant climate-related risks, and the impact of those threats to local economies, infrastructure, property, agriculture, natural resources, and human populations. Often, the greatest need is not for the creation of new data or information, but tools and assistance to navigate the wide array of products and resources already available.

In addition, coordination among and within Federal agencies to ensure delivery of these resources, as well as alignment of policies and practice in support of climate resilient planning and projects by State and local governments, Tribes, and territories, is vital. As the challenge of recovery from climate-related disasters increases, communities will need well-coordinated, well-managed, and collaborative assistance from Federal agencies that leverages and supports existing regional, state, tribal, territorial, and local knowledge networks.

The following recommendations offer ways the Federal Government can shape programs, policies, investments, information sources, and other forms of assistance to ensure that all State and local governments, Tribes, and territories have the capacity to evaluate their particular climate vulnerabilities and act to build resilience.

Children in Philadelphia enhance local green stormwater infrastructure with spring plantings. Photo Credit: *Philadelphia Water Department.*

7.1 Provide data, tools, and guidance at a scale sufficient to guide decision-making and investments. Decision makers at the state, local, tribal, and territorial levels need consistent, geographically specific, and accessible information and tools to identify climate risks and support resilience planning in their communities. The Federal Government should ensure that these efforts are supported by the best-available science through continued research and development of policies, guidance, and a centralized toolkit with resources to help jurisdictions identify climate risks and vulnerable populations, and take steps to increase climate resilience and preparedness. Building on www.climate.data.gov and the Climate Resilience Toolkit currently under development, all climate information should be delivered through a single portal, and uniform standards for climate data should be used to ensure consistency and compatibility across Federal agencies.

Actions to advance this recommendation include:

7.1.1 Develop consistent and regionally- and locally-appropriate sea level rise, storm surge, and Great Lakes water level projections. All Federal agencies should adopt a consistent method for projecting relative sea level rise and Great Lakes water levels and use standardized scenarios across all agencies that accurately represent the range of projected changes, taking into account regionally- and locally-specific conditions.

7.1.2 Create a central Federal repository of hazard maps at the State level. Currently USGS, FEMA, and other agencies maintain maps separately.

7.1.3 Support the delivery of downscaled climate data and the development of regional and sub-regional impact projections and mapping to ensure the availability of data and information at a resolution that is relevant to local decision makers.

7.1.4 Provide guidance for choosing and using existing climate change scenarios and climate impact projections for decision-making, including vulnerability and risk assessments or evaluations.

Cal-Adapt
California

Cal-Adapt[40] is a web-based tool that provides reliable and easy access to the wealth of climate data and information available, through interactive visualizations, to support efforts to prepare for climate impacts in the State of California. Cal-Adapt allows the public to identify potential climate change risks in specific geographic areas throughout the State. Users can query by location or click on an interactive map to explore what climate impacts are likely to occur in their area of interest. Cal-Adapt synthesizes volumes of existing climate change scenarios and climate impact research and presents it in an easy-to-understand graphical format at a scale that allows local governments throughout the state to use Cal-Adapt to inform local planning efforts and policy development.

7.2 Foster and support cross-jurisdictional and regional cooperation.
The experiences of communities affected by acute and long-term climate change impacts offer good lessons for how to build secure and sustainable food, water, energy supply, transportation, and natural resource management systems. Regional organizations such as county associations, metropolitan planning organizations, councils of governments, coordinating councils, regional infrastructure exchanges, and climate collaboratives have developed partnerships and programs that cater to unique regional attributes, natural systems, policy frameworks, governance structures and political realities. For this reason, the Federal Government should work more actively within these existing and emerging frameworks to support resilience and preparedness efforts, while supporting the development of regional frameworks in parts of the country that may not currently have such structures in place. Federal agencies should increase participation with regional organizations and partners and help build capacity to develop best practices and programs tailored to the unique regional impacts of climate change.

[40] See http://cal-adapt.org/

Actions to advance this recommendation include:

7.2.1 Increase support for and incentivize efforts that bring together groups of States, territories, counties, localities, and Tribes to leverage Federal resources more efficiently and collaborate across jurisdictional lines to develop regional indicators, projections, planning tools, and response options, and to implement joint climate preparedness and resilience strategies. Examples include establishing partnerships (like the Western Watershed Alliance) or using Federal programs to fund voluntary collaborations across jurisdictions.

7.2.2 Provide clearer pathways and remove barriers to Federal funding for regional and cross-jurisdictional and/or multi-agency collaborations, integrating climate resilience and preparedness strategies, to maximize efficiencies associated with successful on-going collaboration. Actions could include developing criteria for incorporating these collaborations as an allowable entity for Federal grants and funding programs.

7.2.3 Identify resources, research, training, and technical assistance that could be provided or leveraged by relevant regional Federal facilities (e.g. DOE National Laboratories, Department of Defense (DOD) installations and facilities, etc.) to help regions build climate preparedness through research, capacity building, partnerships, engagement in regional collaboratives or other efforts to assess vulnerabilities and improve regional resilience.

Southeast Florida Regional Climate Compact

"Even though our Regional Climate Action Plan[41] leaves it up the individual county or city to implement the plan's 110 recommendations in ways which works best for each, we have found it makes fiscal and practical sense to work together. It is this spirit of cooperation, the ability to share, trust, and learn from each other, which has led to accelerated action throughout our region—a region so large it accounts for roughly one third of Florida's population. And while all of this gives us great reason to celebrate success, the truth is, we could not have done it without the expertise of our Federal partners."

- **Kristin Jacobs, County Commissioner, Broward County, Florida**

7.3 Create a Climate Resilience Corps to boost community capacity.

Local jurisdictions could greatly benefit from focused climate resilience and preparedness expertise provided by programs such as those established by The Corporation for National and Community Service. A Climate Resilience Corps should be established to provide technical assistance, guidance, and on-the-ground support to help communities advance climate preparedness. This program should leverage existing programs such as Citizen Corps, FEMA Corps, and other national service programs. The Climate

Power Corps members help install and maintain green stormwater infrastructure in Philadelphia. Power Corps supports youth workforce development and environmental stewardship and resilience.
Photo Credit: *Philadelphia Water Department.*

[41] See "Southeast Florida Regional Climate Change Compact Counties: Regional Climate Action Plan," http://www.southeastfloridaclimatecompact.org/wp-content/uploads/2014/09/regional-climate-action-plan-final-ada-compliant.pdf

Resilience Corps should provide technical support to build community capacity; support climate preparedness and resilience planning; support community action and engagement on climate change; train and engage a new generation of youth and educators to lead on climate resilience; promote community education and training on climate resilience; and spur and support citizen-centric preparedness and training. The Climate Resilience Corps should focus on assisting those communities that lack capacity to address the planning and implementation efforts necessary for a community to become more resilient to the impacts of climate change.

7.4 Increase climate literacy and public awareness.

A major barrier to increasing community resilience and reducing the risks of climate change is a lack of public awareness and understanding of the public health and other effects of climate change. An educated and engaged populace is essential to obtain the public support necessary for effective actions to occur and be sustained. Education and training is needed to make clearer the link between how the climate is changing and what the impacts are on the lives of citizens. The Federal Government should develop and make available communications and educational tools and resources that can be adapted to local needs. A cooperative and conscientious strategy is needed to advance climate education and literacy, weave climate impact messages across Federal programs, and utilize high-level and diverse messengers to communicate about the risks of climate change and the benefits of taking steps to reduce these risks.

Actions to advance this recommendation include:

7.4.1 Develop resources for educators based on the National Climate Assessment and other sources of best-available and locally-relevant science, including incorporation of local and traditional knowledge where appropriate.

7.4.2 Coordinate Federal activities on climate communications to develop clear, consistent, and unified messages on climate risks, including the impacts to human health. Provide resources to State and local governments, Tribes, and territories to access these messaging tools.

7.4.3 Senior Federal health officials (e.g., the U.S. Surgeon General, the Director of the CDC, and others) should highlight the public health impacts of climate change and public health announcements should include information about relevant links between climate change and the personal behavior or health threat being considered.

MADE CLEAR
Maryland and Delaware

The Maryland and Delaware Climate Change Education, Assessment and Research (MADE-CLEAR) program is supported by the National Science Foundation as a member of the Climate Change Education Partnership, through a grant awarded to the University System of Maryland. MADE-CLEAR addresses Maryland and Delaware's shared regional climate change concerns and aligns with the States' STEM education emphasis. Its primary goal is to build partnerships among state universities, public schools, informal science education institutions, Federal agencies, and the private sector to support climate education. Currently, MADE-CLEAR is advancing climate science as a part of the curriculum in K-12 classrooms, informal science education programs, and university courses; developing new pathways for teacher training and development in climate science education; engaging in research on how students learn climate content; and enhancing public outreach on climate policy and science.

Conclusion

Task Force members share a commitment to continue collaborating with the Administration as these recommendations are implemented. The Administration has already made progress by acting upon good ideas that have emerged through this process over the past year. For example, at the Task Force meeting in Washington DC on July 16, 2014, President Obama announced a series of new actions[42] responding to the Task Force's input. There is considerable work ahead that will require deliberate coordination across all levels of government and with community leaders. Moving forward, the Administration should develop a transparent and structured process for implementing the recommendations of this Task Force and should continue to engage State and local governments, Tribes, and territories in dialogue throughout the development of responsive polices and initiatives. Additionally, the Administration should:

- **Designate a senior Administration official to coordinate across Federal agencies on the implementation of the Task Force's recommendations.**

- **Establish implementation benchmarks and a process for reporting on progress.**
  The Administration's implementation strategy should include mechanisms to track actions and establish accountability going forward. Task Force members stand ready to support these activities and should continue to receive regular report-outs on implementation actions. Opportunities to provide feedback on progress through a convening meeting or other information-sharing forum should also be created within one year's time.

[42] See "Fact Sheet: Taking Action to Support State, Local, and Tribal leaders as They Prepare Communities for the Impacts of Climate Change," http://www.whitehouse.gov/the-press-office/2014/07/16/fact-sheet-taking-action-support-state-local-and-tribal-leaders-they-pre

Appendix A: Definitions

Adaptation means adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects.[43]

Preparedness means actions taken to plan, organize, equip, train, and exercise to build, apply, and sustain the capabilities necessary to prevent, protect against, ameliorate the effects of, respond to, and recover from climate change related damages to life, health, property, livelihoods, ecosystems, and national security.[44]

Resilience means the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. [45]

Risk means a combination of the magnitude of the potential consequence(s) of climate change impact(s) and the likelihood that the consequence(s) will occur.[46]

Vulnerability means the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

[43] Executive Order No. 13653, 3 C.F.R. 7 (2013). Print.
[44] Ibid.
[45] Ibid.
[46] Bierbaum, R., et. al "Ch. 28: Adaptation." *Climate Change Impacts in the United States: The Third National Climate Assessment*, http://nca2014.globalchange.gov/report/response-strategies/adaptation

Appendix B: Abbreviations

BMP – Best Management Practices

BRACE – Building Resilience Against Climate Effects

CDC – Centers for Disease Control

CEQ – Council on Environmental Quality

DOD – Department of Defense

DOE – Department of Energy

DOI – Department of the Interior

DOT – Department of Transportation

EOP – Executive Office of the President

EPA – Environmental Protection Agency

FTA – Federal Transit Authority

FEMA – Federal Emergency Management Agency

FERC – Federal Energy Regulatory Commission

FHWA – Federal Highway Administration

GAO – Government Accountability Office

HMGP – Hazard Mitigation Grant Program

HUD – Department of Housing and Urban Development

IGA – Intergovernmental Affairs

NEPA – National Environmental Policy Act

NFIP – National Flood Insurance Program

NOAA – National Oceanic and Atmospheric Administration

PACE – Property Assessed Clean Energy

PHEP – Public Health Emergency Preparedness

SBA – Small Business Administration

TIGER – Transportation Investment Generating Economic Recovery

USACE – U.S. Army Corps of Engineers

USDA – U.S. Department of Agriculture

USGCRP – U.S. Global Change Research Program

USGS – U.S. Geological Survey

Appendix C: Acknowledgements

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