SUSTAINABILITY IN A TIME OF CLIMATE CHANGE:

DEVELOPING AN INTENSIVE RESEARCH FRAMEWORK FOR THE PLATTE RIVER BASIN AND THE HIGH PLAINS

PROCEEDINGS FROM THE 2008 CLIMATE CHANGE WORKSHOP, MAY 19-22
HOSTED BY THE UNIVERSITY OF NEBRASKA–LINCOLN & U.S. GEOLOGICAL SURVEY

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Sustainability in a Time of Climate Change: Developing an Intensive Research Framework for the Platte River Basin and the High Plains
A report of the 2008 Climate Change Workshop, May 19-22, North Platte, NE.

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"Climate change is real. It's no longer a question of who's responsible or whether it's real. It's a question of what are we going to do about it."
- Tom Armstrong, USGS senior adviser of global change programs

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Foreword

The Climate Change 2008 Conference, "Sustainability in a Time of Climate Change: Developing an Intensive Research Framework for the Platte River Basin and the High Plains" is the result of an exciting partnership between the University of Nebraska–Lincoln (UNL) and the U.S. Geological Survey (USGS).

In October 2007, USGS scientists and managers visited a host of university scientists and leaders on the UNL campus to learn more about one another's research related to climate change science and explore the possibilities for collaboration and partnership. These discussions clearly highlighted that we had many areas of mutual interest. As a result, a larger, more comprehensive conference was planned, the outcomes of which are documented in this report.

Because of its long history of science, monitoring, studying and assessing our nation's natural resources, the USGS is playing a leading role in the federal government's research programs addressing climate variability and change and its impact on our resources. Similarly, UNL has been a leader in studying the natural resources of Nebraska and the region, and the interactions of people with these resources. Nebraska's great resources – the Platte River system, the High Plains aquifer, the Sand Hills and our immense agricultural system sustained by these resources – make the state a unique laboratory for studying the effects of climate change.

UNL and USGS believe that by combining our expertise and building on our existing activities in this region, we can develop a comprehensive research plan that will help us find resilient, science-based solutions to the challenges we face in a changing climate. The conference provided an opportunity to learn more about our research and monitoring efforts in the Platte River Basin and the Nebraska Sand Hills. It also enabled us to bring together our scientists and the region's stakeholders and decision-makers to discuss current and future challenges related to impacts of climate change as well as identify tools that could assist them in managing these natural resources across the Great Plains. Research can develop effective solutions only if we are asking the right questions. The perspective provided during the stakeholders conference will be invaluable in informing our research efforts.

We want to extend our thanks to all of the participants for their contributions. We especially want to thank Monica Norby for leading the preparation of the proceedings; Karen Wood and Kimberly Espy for organizing the workshop; and Karen Underwood for leading the logistics for the conference.

We believe that proceedings of this conference can make an important contribution to framing the research agenda that will help us to better understand, adapt to and mitigate the impacts of climate change throughout the nation.

Prem Paul
Vice Chancellor for Research & Economic Development
University of Nebraska–Lincoln

Tom Armstrong
Senior Adviser for Global Change Programs
U.S. Geological Survey

"Our research can only provide solutions if we are asking the right questions."
- Prem Paul, UNL vice chancellor for research and economic development

Executive Summary

The University of Nebraska–Lincoln (UNL) and the U.S. Geological Survey (USGS) are developing a research partnership to better understand, adapt to and mitigate the impacts of climate change in the Platte River Basin and the High Plains. The Climate Change 2008 Workshop, "Sustainability in a Time of Climate Change: Developing an Intensive Research Framework for the Platte River Basin and the High Plains" was designed to inventory our mutual research strengths and resources in this area and to bring key stakeholders and decision-makers into the process to build further partnerships.

The native grasslands and farmlands of Nebraska comprise one of the most productive agricultural areas in the world – productivity made possible by the Platte River, which rises in the Rocky Mountains and transects the state, and the High Plains aquifer, the largest groundwater system in North America. These systems sustain a major agricultural economy, native grasslands, river ecosystems, and the North American Central Flyway, which is vital to the survival of many migratory bird species, including threatened and endangered species.

The native grasslands and farmlands of Nebraska comprise one of the most productive agricultural areas in the world – productivity made possible by the Platte River and the High Plains aquifer.

Climate change may present a threat to these critical ecosystems. A lack of robust, dynamic scientific data characterizing this unique ecosystem, including its geologic framework, aquifers, surface waters, land cover, geomorphology and wildlife, combined with deficiencies in modeling capabilities, impede the accurate forecasting needed for the informed decision-making that will enable us to adapt to the impacts of climate change.

Addressing these issues will require collaboration involving partners from academia, state and federal agencies, nongovernmental organizations and the private sector. The participants in the 2008 Climate Change Workshop represented all of these groups and provided valuable perspectives about their challenges and research needs – the beginning of a broad-based partnership to develop a research framework for understanding and adapting to the potential economic and ecological effects of climate change.

A national climate effects network

The Department of the Interior has developed a model for a national climate effects network that will detect changes in climate, landscape and species composition; provide scientific analysis of those findings in support of adaptation or mitigation strategies; and develop information dissemination and decision support systems that will enable decision-makers to make cost effective, scientifically rigorous management and policy decisions. The ultimate goal of this system is to create the capacity for the next generation to protect and sustain our resources as we face a changing climate.

Creation of a national network will require a system of large-scale regional research sites – Collaborative Observation and Research Ecoregions (CORE) – that represents the diversity of major ecosystems across the U.S. One of the potential CORE sites identified by USGS is grasslands in the central U.S. The Platte River Basin and High Plains include a major river basin already showing the effects of a warmer and drier climate and a fragile ecosystem that can act as sentinel for detecting early change. Existing USGS monitoring programs in the region, including the National Water Quality Assessment (NAWQA) program and the High Plains Regional Groundwater Study, are essential to building a CORE and are complemented by many other USGS and UNL research programs focused on climate, water resources, ecological diversity and other key areas.

The Platte River Basin and the High Plains as a natural laboratory

The Platte River Basin, the Nebraska Sand Hills, the High Plains aquifer and the grasslands and farmlands of the High Plains comprise a diverse natural laboratory for studying the effects of climate change. In the first two days of the climate change workshop, 80 USGS and UNL researchers traveled to research sites in this region to develop a broader knowledge of existing research and a deeper understanding of the challenges of managing this important landscape.

The Platte River Basin: Agriculture, wildlife, industry and urban needs

The Platte River rises from snowpack in the Rocky Mountains and flows 900 miles across the plains, fed by tributaries whose source is the High Plains aquifer and emptying into the Missouri River at Plattsmouth, Neb. The Platte River Basin drains an area of almost 90,000 square miles that sustains thousands of acres of lakes and wetlands, and provides a staging and resting area for the North American Central Flyway, which is vital to the survival of a majority of Western Hemisphere waterfowl.

Sandhill cranes in the Platte River
Photo courtesy Nebraska Game and Parks Commission

The Platte River Basin also sustains one of the world's major agricultural economies. Eastern Nebraska is the western edge of the U.S. Corn Belt, the most productive agroecosystem on the planet. This region produces more than 40 percent of the world's corn and soybean supplies. The irrigated corn that accounts for 14 percent of total corn production is produced almost entirely in the Great Plains with water drawn from the Platte River, its tributaries and the High Plains aquifer. Nebraska also is the nation's second-largest producer of corn ethanol, which increases the demand for both corn and water.

Changes in water and land use, changing patterns of snowmelt in the Rockies, a prolonged seven-year drought and increasing demands for irrigation have reduced flows in the Platte River, transformed its channel and altered adjacent wet meadows. These changes raise questions about the sustainability of migratory and resident bird species and other biota in the basin. The increasing global demand for crops for food and fuel and urban expansion at the western and eastern ends of the river put greater demand on water resources for irrigation, industry and urban needs.

The Nebraska Sand Hills: A sentinel system

The Nebraska Sand Hills is a unique region of 19,300 square miles of grass-stabilized sand dunes lying atop the High Plains aquifer. The Sand Hills is the largest sand dune formation in the Western Hemisphere and one of the largest grass-stabilized dune regions in the world. Beneath the Sand Hills lies the High Plains aquifer, the largest groundwater system in North America and possibly the world, spanning more than 174,000 square miles from South Dakota to Texas. The largest portion of the High Plains aquifer – 67 percent of the total drainable water – lies beneath Nebraska, and the Sand Hills serves as a system for recharging the water in the aquifer.

The fragility and sensitivity of this unique ecosystem makes it an ideal sentinel system for monitoring climate change. UNL research revealed that as recently as 800 years ago a mega-drought stripped the dunes of their vegetation and they became an active, Sahara-like desert. This change likely was induced by a shift in the wind patterns that decreased precipitation – an example of the devastating effects of climate change and the Sand Hills' susceptibility.

An integrated science and monitoring network focused on the sensitive landscapes of the Sand Hills, the High Plains aquifer and the Platte River Basin could provide data and predictive models that will enable planning for mitigation and adaptation to climate change throughout the region and for other ecoregions facing similar challenges.

Identifying research needs for the region

The conference portion of the workshop featured four symposia addressing key issues in the region, with panel discussions involving representatives of local, regional and federal organizations and agencies and interaction with audience members. Following the conference, UNL and USGS researchers met in breakout sessions to begin preliminary planning for the research framework based on the recommendations of the stakeholders and their tours of the region. Four major research focus areas were identified.

The Nebraska Sand Hills is one of the largest grass-stabilized dune regions in the world.

- *Climate change past, present and future: the Sand Hills as a sentinel system.*
  The long-term record of climate change recorded in the dunes of the Sand Hills can give us insights into processes occurring today that may be analogous to changes that occurred 10,000 or 50,000 years ago and enable us to determine how future scenarios may differ from the processes of the past.

- *Impacts of climate change on landscapes, biodiversity and natural resources.*
  The Platte River Basin and the High Plains aquifer comprise complex ecological transitions and economic and social systems that reflect the pronounced changes in precipitation, temperature, altitude and soils across the region. Water availability, water use, agricultural and social viability are all sensitive to climatic change.

- *Carbon management: The interaction among agriculture, energy, infrastructure and climate.*
  Agriculture, energy production and use, infrastructure and climate are tightly interwoven. The potential for rapid and unpredictable changes in temperature and the linked threats of decreasing water quantity and quality pose great risk to the sustainability of this critically important food- and fuel-producing region.

- *Climate effects on water availability for human and ecological needs.*
  Water must be available for both human needs, such as irrigation for crops, and for ecological needs, such as the preservation of critical wildlife habitats. How much water can be withdrawn for irrigation and energy production, and

how much must be left in the system to retain ecological integrity and the capability for resiliency? These are crucial questions as a changing climate alters patterns and timing of snowmelt and precipitation that provide water for the region.

Stakeholder and decision-maker recommendations

The stakeholders and decision-makers identified many challenges and research needs, but the following *cross-cutting recommendations* were common among topics.

- Accurate long-term predictions of precipitation and temperature
- Ability to downscale climate, ecological and hydrological models
- Improve groundwater, surface water and ecological models
- More research on improving the efficient use of water, especially in irrigation
- Develop risk management tools that enable producers to make field-scale decisions
- Increased and more extensive monitoring networks to gather needed data on the plants and animals in ecological communities
- Develop adaptive management techniques
- Determine optimal uses of land for production of all types of biofuel feedstocks in the region
- Involve agricultural producers in research efforts
- Conduct research on social and cultural changes that will help society adapt to climate change
- Communicate research results in understandable, easily accessible formats
- Increase emphasis on collaborative research

Preliminary planning for the research framework

USGS and UNL researchers met in breakout groups focused on key topic areas to begin developing a research framework. The breakout groups' charge was to determine specific climate effects and response issues in the region and to identify focused long-term research and monitoring questions, taking into consideration the existing USGS and UNL research programs and the issues and challenges raised by the stakeholder panels. Each group also made an inventory of existing monitoring and data collection capabilities and identified gaps in infrastructure, expertise and tools needed to successfully implement the research plan.

Targeted research questions

Topic 1: Climate Change Past, Present and Future: the Nebraska Sand Hills as a Sentinel System

- What can be learned from paleoclimate records of the Sand Hills and applied to models of future climate changes? Does the paleo-hydroclimatologic record provide an analog of the landscape response to climate change of the type predicted for the future?
- How and where would landscape changes in the Northern High Plains, and specifically the Sand Hills, be initiated as atmospheric circulation and climate change? What are the spatial and temporal trajectories?

Topic 2: Impacts of Climate Change on Landscapes, Biodiversity and Natural Resources

- How will climate change affect landscapes, in particular agricultural landscapes?
- How will climate change alter the hydrology in the Sand Hills and what are the interconnections between hydrologic and ecological environments

in the High Plains (e.g., snowpack, runoff and groundwater-surface water interactions)?
- What are the interconnections (including thresholds and alternative stable states) among the ecological, hydrologic and socioeconomic environments in the High Plains, and what maintains the resilience of this social-ecological system?
- What are the other key variables, such as soil structure, temperature, and human and ecological population levels, driving potentially major shifts in the Great Plains?

Topic 3: Carbon Management: The Interaction Among Agriculture, Energy, Infrastructure and Climate
- How much water is needed to sustain food production, fuel production, aquatic organisms/systems and wildlife – currently and with climate change?
- What is a sustainable amount of land use for agriculture and for aquatic organisms/systems and wildlife?
- How will climate change increase or decrease land and water use for crops, range/pasture and livestock production?
- What adaptive management strategies would minimize risk and optimize opportunities for food and fuel production?
- How can we assess the carbon balance and carbon sequestration potential of agriculture and energy industries?

Topic 4: Climate Effects on Water Availability for Human and Ecological Needs
- What is the current understanding of contemporary hydrologic and carbon cycle variability and its controls?
- At what hydrologic thresholds do High Plains ecosystems begin to shift in response to climate change/warming?
- How can regional or basin-scale hydroclimatic models quantify the feedback interactions and their uncertainties?
- How does hydrologic variation due to climate change affect agriculture and other human activities in the Platte River Basin and the High Plains? How do we adapt these activities and what are the optimal thresholds required to sustain them in the long term?
- What are the best indicators, and where are the best locations to monitor water and ecological processes to detect climate impacts and change thresholds?

Cross-cutting research questions
- What are the patterns of variability? Are there precursor signals of abrupt events?
- What are the key variables and thresholds in ecological and hydrological systems?
- Is there a critical subset of data that gives us the widest range of indicators of climate change?
- How can monitoring data be integrated into management strategies?
- What kind of risk management strategies and decision support tools can be developed to help communities adapt to extremes in climate?
- How can adaptive management methods be woven into research plans?

Cross-cutting research infrastructure needs and tools to support decision-making

Development of research infrastructure and tools to support research, decision-making and dissemination of research results is essential to developing cost-effective, science-based management and policy decisions. The breakout groups identified the following infrastructure and tools as critical to the research framework.

- Additional research/monitoring stations for stream gaging, groundwater levels, climate and recharge at key locations
- Ecological research/monitoring stations
- Large-scale, landscape level eddy-covariance tower facilities to measure CO_2, NO_2 and other fluxes at key locations
- Life-cycle analysis tools to measure greenhouse gas emissions from managed and natural ecosystems
- Web-based decision support tools to provide improved capabilities for real-time resource management, and to support community, stakeholder and policymaker access and education
- Broad-scale cyberinfrastructure to support scientific communication and data analysis and management across scientific communities
  - Data integration framework to provide common access to disparate data sets
  - Grid computing tools for high-performance data analysis
  - Real-time data network and data standards
- Modeling
  - Mathematical and statistical modeling techniques for regionalizing climate predictions, for up- and down-scaling and running scenarios
  - Models linking field to watershed to regional modeling of crop/pasture/livestock water requirements based on historical and future climates
  - Expanded precision for regional groundwater and surface water models
- Real-time sensors and wireless sensor networks
- Economic and risk analysis tools

The Platte River Basin and the High Plains can provide an ideal large-scale regional research site representing a critically important ecoregion in the continental U.S.

Next steps: Implementing the research framework

A team of UNL and USGS scientists is synthesizing recommendations from the conference, reviewing the preliminary planning documents from breakout groups and developing the research framework. When a draft framework has been completed, the team will bring together key partners from academia, state and federal agencies, nongovernmental organizations and the private sector to provide input. The final steps will be to create partnerships, identify funding opportunities and obtain funding for new and existing monitoring and research programs and decision support tool development to fill identified research gaps.

The long-term goal of the USGS-UNL research partnership is to create an intensive research framework for an integrated, real-time knowledge base and system for monitoring responses to climate change. This system will support more informed policy, stewardship and legal decisions to balance competing ecological and human socioeconomic demands and to ensure sustainable management of the important ecosystems and limited water resources of the region in the context of climate change. An integrated, adaptive management approach will serve as a scientific foundation for conserving surface and groundwater resources, threatened grassland and wetland ecosystems, and mid-continental bird populations, while maintaining the economic viability of one of the world's most important agricultural regions. This collaborative approach is critical for understanding the complex challenges and responses to climate change. The Platte River Basin and the High Plains can provide an ideal large-scale regional research site that is representative and nationally important, and will provide scientific discoveries with broad national and international value.

CHAPTER 1 INTRODUCTION

INTRODUCTION

The native grasslands and farmlands of Nebraska comprise one of the most productive agricultural areas in the world – a level of production made possible by a wealth of water resources. Rising in the Rocky Mountains in Colorado and Wyoming, the South and North Platte Rivers meet in Nebraska to become the great Platte River, which flows 500 miles, transecting the state. Beneath the Platte River Basin lies a large portion of the High Plains aquifer, the largest groundwater system in North America. Together these systems sustain a major agricultural economy, native grasslands, important river ecosystems, thousands of acres of lakes and wetlands and the North American Central Flyway, which is vital to the survival of hundreds of Western Hemisphere migratory bird species, including threatened and endangered species.

Climate change and the accompanying pressures may present a major threat to this critical ecosystem. More informed policy, stewardship and legal decisions are required to balance competing ecological and human socioeconomic demands and to ensure long-term sustainability of the High Plains. Yet a lack of robust, comprehensive scientific data characterizing this unique ecosystem, including its geologic framework, aquifers, surface waters, land cover and geomorphology, combined with a lack of long-term monitoring capabilities and deficiencies in modeling capabilities, impede the accurate forecasting needed for the informed decision-making that will enable us to adapt to the impacts of climate change.

The complex interactions between ground and surface water in the grassland ecosystem are poorly understood, particularly in the context of climate change-induced drought, greater pressures on water resources related to biofuel production and urbanization, and the pressures to boost agricultural yields to feed a growing world population and meet energy needs while preserving natural and cultural resources. Efforts such as the Platte River Cooperative Hydrology Study, a multi-agency, multi-state study aimed at developing computer models to increase understanding of the relationship between ground and surface water in the Platte River Basin, need to be extended throughout the Platte River, High Plains aquifer and Sand Hills ecosystems. Expanded, long-term monitoring of the ecological communities of the region is needed to provide the basic information required for ecological models. Retrospective analysis of ecological data and paleo-science examining long-term evidence of past climatic conditions and effects provide critical information.

Platte River Valley

Such studies can have implications not only for Nebraska, but for the entire High Plains region. The development of advanced wireless sensor networks and modeling and simulation infrastructures provides an opportunity to gather critical data and to develop 21st century decision support tools to help stakeholders sustainably manage resources in the Platte River Basin and the High Plains in a time of climate extremes and climate change.

The University of Nebraska-Lincoln (UNL) and the U.S. Geological Survey (USGS), with key regional stakeholders and decision-makers, are developing a research partnership to address these issues. The long-term goal of this research partnership is to create an intensive research framework for an integrated, real-time knowledge base and system for monitoring responses to climate change. This system will support informed decision-making for sustainable management of important ecosystems and limited water resources in the context of climate change. An integrated, adaptive management approach will serve as a scientific foundation for conserving surface and groundwater resources, threatened grassland and wetland ecosystems, and mid-continental bird populations, while maintaining the economic viability of one of the world's most important agricultural regions. It will serve as an important model for managing other major ecoregions where food production and critical habitats rely directly on surface water and groundwater interactions.

A workshop held May 19-22, 2008, in North Platte, Neb., in the heart of the Platte River Basin, High Plains aquifer and Sand Hills systems, brought together scientists, stakeholders and decision-makers to discuss the key research and socioeconomic issues to be addressed by this network, as well as potential designs for a monitoring and research framework. The workshop, which involved 80 UNL and USGS researchers, included two days of field trips to research sites in the Platte River Valley and the Sand Hills, aimed at developing a broader knowledge of the existing research studies and a deeper understanding of the challenges of ecosystem management in this unique landscape.

The workshop was followed by Climate Change Conference 2008, a day-long meeting with more than 150 important stakeholders and decision-makers representing agriculture, water, energy and wildlife/conservation interests. Four symposia addressing key issues featured panel discussions with representatives of local, regional and federal organizations and agencies, and interaction with audience members. Following the conference, UNL and USGS researchers met in breakout sessions to begin preliminary planning for the research framework based on the input from stakeholders and their tours of the region. This report documents the results of those four days of discussion.

CHAPTER 2

OVERVIEW OF UNL AND USGS RESEARCH IN THE REGION

The Lower Platte River Valley and Associated Agricultural Lands

The Platte River rises from snowpack in the Rocky Mountains and flows 900 miles across the plains, is fed by tributaries arising from the High Plains aquifer, and empties into the Missouri River at Plattsmouth, Neb. The Platte River Basin drains an area of approximately 90,000 square miles that encompasses alpine headwaters, high desert, bountiful cropland, expanding urban centers and vast grasslands. It sustains thousands of acres of lakes and wetlands, and provides a staging and resting area for the North American Central Flyway, which is vital to the survival of a majority of Western Hemisphere waterfowl, including the threatened and endangered whooping crane, piping plover and least tern.

The Platte River Basin also helps sustain one of the world's major agricultural economies. Eastern Nebraska is the western edge of the U.S. Corn Belt, a region that produces more than 40 percent of the world's corn and soybean supplies. Irrigated corn, which accounts for 14 percent of total corn production, is produced almost entirely in the Great Plains from water drawn largely from the Platte River, its tributaries and the High Plains aquifer. Nebraska also is the second-largest producer of corn ethanol, increasing the demand for both corn and water.

Changes in water and land use, a prolonged seven-year drought and increasing demands for irrigation have reduced flows in the Platte River, transformed its channel and altered adjacent wet meadows. These changes in the hydrology of the river and the structure of riparian habitats raise questions about the sustainability of migratory and resident bird species and other wildlife in the basin. The increasing global demand for crops for food and fuel and urban expansion at the western and eastern ends of the river puts greater demand on water resources for irrigation, industry and households.

The Platte River

A 385-mile, one-day tour of USGS and UNL research sites in the Platte River Basin highlighted the numerous, complex issues surrounding water in the region and how climate change may affect these issues and pose new challenges. At UNL's South Central Agricultural Research Laboratory, agronomists and engineers focus on how to achieve irrigated crop yields well above current average yields while reducing the amount of irrigation water and the potential for nutrient losses – a major global issue as populations grow, available arable land shrinks and water supplies may be reduced by a warmer and drier climate. At the Platte River near Kearney, Neb., the heart of the 100-mile strip of the river that is the spring resting place for the Sandhill and whooping cranes, a USGS wildlife biologist discussed how cranes may be adversely affected by encroachment of woody vegetation on the river due to declining river flows in the Platte and changing cropping patterns.

OVERVIEW OF UNL AND USGS RESEARCH IN THE REGION

The Lower Platte River Valley and Associated Agricultural Lands

USGS and UNL scientists have been drilling test holes to monitor groundwater and assess recharge in the Platte River Basin since the 1930s, an extremely valuable record in determining potential effects of climate change. These data are used to build regional hydrogeologic studies and groundwater models that enable characterization of the aquifers and geology of Nebraska and an understanding of groundwater-surface water interactions. New methods for characterizing groundwater, such as magnetic resonance soundings, are less intrusive and less expensive means of improving the accuracy of groundwater flow models.

The following is a selection of the research projects visited during the Platte River Valley tour. Abstracts of these projects and others can be found at http://research.unl.edu/events/climatechange2008/abstracts.pdf.

- *Ensuring the Environmental Sustainability of Biofuel Systems*
  Ken Cassman, Nebraska Center for Energy Sciences Research at UNL, and Suat Irmak, UNL Department of Biological Systems Engineering

- *Characterizing Recharge Across Climatic and Land Use Regions of the Great Plains*
  Greg Steele, USGS Nebraska Water Science Center

- *Remote Sensing and Geographic Information Systems: Tools for Climate-Change Research*
  Sunil Narumalani, UNL Center for Advanced Land Management Information Technologies

- *Evaluating the Role and Importance of Ecological Diversity in Creating Ecological Resilience*
  Chris Helzer, The Nature Conservancy, and Craig Allen, USGS/UNL

From left: Jim Cannia and Jim Goeke

- *Potential Risks to the Midcontinent Population of Sandhill Cranes from Climate Change*
  Gary Krapu, USGS Northern Prairie Wildlife Research Center

- *Water Balance of Riparian Woodlands Along the Platte River, Nebraska*
  Dave Rus, USGS Nebraska Water Science Center

- *Exchanges of Carbon Dioxide and Water Vapor in Key Ecosystems*
  Shashi Verma, UNL School of Natural Resources

- *Shaping Drought on the Plains: Adding Climate Change to the Mix*
  Mike Hayes, UNL National Drought Mitigation Center

- *Test Hole Drilling as Part of Aquifer Optimization*
  Jim Goeke, UNL School of Natural Resources

- *Geophysics for Hydrologic Characterization*
  Jim Cannia, USGS Nebraska Water Science Center

The Nebraska Sand Hills and the High Plains Aquifer

The Nebraska Sand Hills is a 19,300-square-mile area of ancient grass-covered sand dunes – the largest such dune field in the world. The Sand Hills has been called a "desert in disguise," a desert of dunes held in place by a thin layer of vegetation that is extremely sensitive to changes in precipitation. This unique ecosystem supports one of the most productive cattle-raising economies in the nation, producing almost 19 percent of the U.S. beef supply. Beneath the Sand Hills lies the primary reservoir of the High Plains aquifer, one of the world's largest fresh water aquifers and the major water supply for the central plains region of the U.S. This reservoir contains more than 2 billion acre-feet of water, which feeds the Niobrara, Snake, Elkhorn, Dismal, Calamus and Loup Rivers and the many streams that flow out of the Sand Hills. This water-rich but fragile environment provides a natural laboratory for identifying subtle changes in climate and their effects.

In a day of travel through 285 miles of the Sand Hills, UNL and USGS scientists discussed existing research projects examining key aspects of the region, including stream flow; recharge of the aquifer; paleohistory of the dunes; cattle feeding and grazing; rangeland ecology; the effects of precipitation, evapotranspiration and carbon dioxide fluxes on grassland productivity; and the ecology of herbaceous systems. What became clear was the potential the Sand Hills and the High Plains aquifer hold as early indicators of climate change.

The Sand Hills can provide a sensitive barometer of changing climate, and UNL's Gudmundsen Sandhills Laboratory (GSL) is a true natural laboratory for this study. The 12,800-acre ranch represents all the physiographic settings present in the Sand Hills – lakes, streams, wetlands, wet meadows, dry valleys and uplands – making it an ideal laboratory for studying the hydrogeology and ecology of the region. GSL sits atop an area of the High Plains aquifer where the saturated thickness (the thickness of the aquifer completely filled with water) is more than 1,000 feet. Yet the water lies so near the surface that wet meadows are created in the valleys where the water table lies less than a meter below, or at, the surface.

However, the prairie vegetation that covers the dunes relies on precipitation. Although the Sand Hills dunes are now stabilized by this cover, UNL research shows that unprecedented prolonged droughts during the past 18,000 years killed the stabilizing grasses, and the dunes began to blow and move. The most recent dune activity was only 800 years ago. Scientists believe it was caused by a shift in the direction of the spring-summer prevailing winds that previously brought moisture from the Gulf of Mexico. A slight westward shift – as little as a few hundred miles – could have been enough to devastate vegetation, resulting in wind erosion and dune migration.

Another example of a climate change indicator is USGS stream flow research showing the amazingly consistent flows of the Dismal and Middle Loup Rivers, which are spring-fed by the aquifer, unlike many western streams (and the Platte River) that are fed by snowmelt. Flows in these rivers have deviated little since 1965 and have remained 10 percent higher, on average, than in 1970. This consistent flow makes any changes in stream flow an excellent early indicator

OVERVIEW OF UNL AND USGS RESEARCH IN THE REGION

The Nebraska Sand Hills and the High Plains Aquifer

of subtle climate change effects on the aquifer, stream flow and its watershed controls.

The following is a selection of the research projects visited during the Sand Hills tour. Abstracts of these projects and others can be found at http://research.unl.edu/events/climatechange2008/abstracts.pdf.

- *Dismal River Long-term Integrated Monitoring*
  Ron Zelt and Bob Swanson, USGS Nebraska Water Science Center

- *Hydrogeologic Investigations at Gudmundsen Sandhills Laboratory*
  Jim Goeke, UNL School of Natural Resources

- *Beef Cattle Research in the Sand Hills*
  Rick Funston, UNL Department of Animal Science

- *Recent Insights into the Geologic History of the Sand Hills*
  David Loope, UNL Department of Geosciences

- *Rangeland Ecology and Grazing Research in the Nebraska Sand Hills*
  Jerry Volesky, UNL Department of Agronomy and Horticulture

- *Effects of Precipitation and Groundwater on Grassland Productivity in the Nebraska Sand Hills*
  I: Water – Dave Billesbach, UNL Department of Biological Systems Engineering
  II: Carbon – Tim Arkebauer, UNL Department of Agronomy and Horticulture

Dune blowout in the Sand Hills

- *The Nutrient Network*
  Johannes (Jean) M.H. Knops, UNL School of Biological Sciences

- *The Value of Longterm Ecological Research in the Sand Hills*
  Svata Louda, UNL School of Biological Sciences

- *Potential Contributions of Behavior and Physiology to an Understanding of the Impact of Climate Change on Animals*
  Gwendolyn Bachman, UNL School of Biological Sciences

- *Using Duckweed Communities as a Model to Understand the Effect of Climate Change on Food Web Interactions*
  Chad Brassil, UNL School of Biological Sciences

CHAPTER 3

STAKEHOLDERS AND DECISION-MAKERS CONFERENCE

STAKEHOLDERS AND DECISION-MAKERS CONFERENCE

A major goal of the 2008 Climate Change Conference was to bring regional stakeholders and decision-makers into the planning process, to hear their concerns and ideas and to build further partnerships. A day-long meeting with more than 150 important stakeholders and decision-makers representing agriculture, water, energy and wildlife/conservation interests featured four panel discussions of key topics with representatives of local, regional and federal organizations and agencies, and interaction with audience members. The four symposium topics were:

Symposium 1
Watering the Next Century: Sustaining a Resource for the Future

Symposium 2
Biofuels, Water Resources and Climate Change: Solving the Sustainability Puzzle

Symposium 3
Integrating Crop, Livestock and Irrigation Technologies to Ensure Food Security and Environmental Quality

Symposium 4
Invasions and Extinctions as a Consequence of Climate Change

Cross-cutting recommendations from stakeholders and decision-makers

- Accurate long-term predictions of precipitation and temperature
- Ability to downscale models (climate, ecological, hydrological) to areas as localized as a basin and to link models
- Improved groundwater and surface water models
- More research on improving the efficient use of water, especially in irrigation
- Development of risk management tools that enable producers to make better field-scale decisions
- Increased and more extensive monitoring networks to gather needed data on the plants and animals in ecological communities
- Development of sophisticated ecological models
- Development and implementation of adaptive management techniques
- Determine optimal uses of land for production of all types of biofuel feedstock in the region
- Involve agricultural producers in research efforts to ensure that effective solutions are designed and will be adopted
- Conduct research on social and cultural changes that will help society adapt to climate change
- Communicate research results in understandable, easily accessible formats
- Increase emphasis on collaborative research

Symposium 1
Watering the Next Century: Sustaining a Resource for the Future

Panelists
Curt Brown, *Director, Research and Development, U.S. Bureau of Reclamation*
Steve Gaul, *Director, Planning and Assistance Division, Nebraska Department of Natural Resources*
Eugene Glock, *Farmer and former staffer for U.S. Senator Bob Kerrey*
Jim Meismer, *Member, Board of Directors, Twin Platte Natural Resources District*
Bob Snoozy, *Senior Vice President of Sales and Marketing, Lindsay Manufacturing*

Moderator
Bob Swanson, *Director, USGS Nebraska Water Science Center*

Each panelist has many years of experience in dealing with water issues and each brings a perspective from a different area of expertise. These include natural resources management at the state government level, research and administration for a federal agency, farming and ranching, public water policy advocacy, staffer for a Nebraska U.S. senator, and irrigation research and development in the private sector.

From left: Gene Glock, Steve Gaul, Bob Snoozy

Effects of climate change
Managing water resources to provide the quantity and quality to meet the needs of agriculture, industry, recreation and urban use is one of the key challenges throughout the western U.S. and certainly in the Platte River Basin and the High Plains. Due to semi-arid conditions, the western U.S. also is one of the areas most likely to be affected by climate change and where effects already are being seen. The panelists identified changes in the timing of weather and climate events and factors affecting water supply and demand as major potential effects of climate change.

Curt Brown, providing the broad perspective of the U.S. Bureau of Reclamation, pointed out that one of the stronger signals of climate change is the warming of winter minimum temperatures. Throughout the Rocky Mountains and into the northwestern U.S. some areas have experienced significantly earlier spring runoff, indicating that mountain snow and ice are melting earlier, Brown said. Because this mountain snowpack is the largest reservoir in the West for storing and managing water, earlier melt and runoff causes significant difficulties managing that water later in the year. This change in the *timing of events* is a major climate change issue.

Warmer minimum winter temperatures also can increase the prevalence of pests, indirectly affecting water quality. An example is the spread of several pine beetle species throughout the Rocky Mountain chain, which has dramatically reduced the number of trees in forests and increased erosion and runoff of silt into drinking water supplies, Brown said.

All panelists spoke of the potential effects of climate change on the water supply, particularly the consequences of reduced precipitation, including snowpack in the Rockies, the major source of water for the upper Platte River. Supply also can be affected by changes in temperature, runoff, the frequency and severity of drought cycles and changes in extreme flood events.

Climate change is likely to increase the demand for water, with higher temperatures possibly causing changes in vegetation and cropping patterns in the High Plains and the Platte River Basin.

Most importantly, higher temperatures result in crops using more water, increasing the need for irrigation – by far the largest use of water in the region. Nebraska has the second-largest number of irrigated crop acres in the U.S. – only California has more – and currently has about 50,000 center pivot irrigation systems. Bob Snoozy, a vice president for pivot manufacturer Lindsay Manufacturing, estimated that there are several hundred thousands of pivot systems nationwide. He also said phenomenal growth in the use of pivot technology is occurring globally in Saudi Arabia, China and other regions.


From left: Curt Brown, Jim Meismer, Bob Swanson

"The challenge for irrigators is very simple. We need to use less water, less energy, less labor, do it in an environmentally friendly manner and do it economically to the benefit of farmers," Snoozy said. Today's pivots use far less water by applying water closer to the soil, and lower pressure systems cut energy costs.

Pivot systems are becoming highly automated and can be run from a cell phone or a laptop computer. They also have the potential to monitor soil moisture and other parameters and are able to apply different amounts of water and chemicals on one square foot of soil at different rates than the surrounding land. These systems could become valuable tools for monitoring climate parameters and supplying climatological and other data from hundreds of thousands of sites, Snoozy said.

Managing water to adapt to climate change

Nebraska is at the forefront of managing water supplies stressed by high demand. In 2002 the Governor's Water Policy Task Force charged the state's 23 Natural Resources Districts (NRDs), which are responsible for monitoring quality and quantity of groundwater, with taking a more proactive approach in the integrated management of surface water and hydrologically connected groundwater. The task force also charged the Nebraska Department of Natural Resources (DNR) with designating river basins as under-appropriated, fully appropriated or over-appropriated. As a result of the task force, in 2004 the state legislature passed LB 962. Steve Gaul of DNR explained that under this law, if a river basin is declared fully appropriated or over-appropriated, drilling of all new wells and the addition of irrigated acres is suspended and DNR must work with the local NRDs to develop an integrated management plan for the basin. The goal is to sustain a balance between water uses and water supplies to protect the economic viability, social and environmental health, safety and welfare of the river basin and maintain it for the near- and long-term, Gaul said. More than half of Nebraska is now under at least a temporary moratorium on high-capacity wells.

DNR is required to conduct an annual evaluation of long-term water supply. Integrated management plans are based on data from the past 20 years, so plans will be affected if climate change impinges on water supply. Under this scenario, past uses will be declared too high, mandating cutbacks to restore sustained balance, which is much more difficult than curbing new or future uses, Gaul said. "However, the plans are flexible. They are a work in progress, which is why research is so important. They need the best scientific information available. We need to get better data."

The Twin Platte South Natural Resources District covers parts of the North and South Platte and Platte River Basins and was declared fully and over-appropriated in 2004, said Jim Meismer, a member of the Twin Platte board for 14 years. The NRD was given three to five years to develop an integrated management plan. It assembled a task force that includes representatives of all of the stakeholders – irrigators, the Nebraska Attorney General's office, municipalities, utilities, DNR, recreational users, legislators and others. The task force is developing a service water model using groundwater data from the multi-agency Platte River Cooperative Hydrology Study to assess the district's total assets and consumptive use. The NRD's plan is to manage water based on consumptive use and to reduce usage by redeeming irrigated acres or giving farmers the option to change their cropping patterns to decrease their consumptive use.

Panelists agreed that progress is being made in the difficult task of addressing transboundary issues where states' laws are inconsistent or even contradictory. The Nebraska, Colorado and Wyoming tri-state Platte River compact was cited as a unique example of collaboration among states; the seven-state Colorado River compact also was noted. Farmer and water policy advocate Eugene Glock noted that farmers, NRDs, municipalities and others impacted by the Kansas-Nebraska Republican River dispute are meeting and negotiating and do not consider state boundaries to be a drawback in reaching a settlement, even though Kansas and Nebraska are still in court.

All panelists emphasized the necessity for collaboration in developing plans for managing water. "We have to bring together all of the people, the users who need the information and the scientists who can provide it, and put them together in a dynamic organization," Brown said.

Research needs

The need for more and better research was the panel's common theme. Specific research needs included:

- Predicting extreme events
- More accurate, longer-term predictions for precipitation and temperature
- Downscaling climate forecasts to a river basin, or even smaller level
- Better data on snowfall and rainfall patterns
- Better data on surface water supply and climate at a basin scale
- Improved groundwater and surface water models
- More automated data – such as stream gaging – to feed into those models

"We have to bring together the users who need the information and the scientists who can provide it, and put them together in a dynamic organization."

- More collaborative research among agencies
- Research on social and cultural changes that will help society adapt to climate change

In response to a question about prediction and linearity of models, Tom Armstrong, USGS senior adviser for global change programs, said this is one of the key difficulties. The predictions are linear, but the impacts of climate change are nonlinear. "We can't look at yesterday and the day before and draw a straight line through them and say, 'This is where we're going for the future thousands of years out,'" Armstrong said. Scientists must examine data based on the best science in the context of uncertainties and non-linearity. When they convey information to decision-makers, they must say, "This is what the models are telling us, but there are uncertainties associated with it," Armstrong said. "We have to give decision-makers information in an accurate, objective, unbiased way. It can't be our best guess. Or if it is, we need to tell them so. We can't just say, 'This is what's going to happen.' That is one of the challenges."

"Farmers need to be ahead of the curve. It's a lot cheaper to prevent something than to cure it."

Glock discussed the need to include farmers and ranchers in the research efforts. This is one way to overcome the agricultural community's skepticism about global climate change, he said. Farmers and ranchers have dealt with extremes in temperatures and precipitation throughout their lives, and some are hesitant to attribute climate changes to global warming.

"I'll put it in the words of a young farmer in his mid-20s, who graduated from the ag college in 2005," Glock said. "I asked him Monday, what do you think about global warming? He didn't even hesitate. 'If this is global warming, bring it on. I've never raised such good crops.' So, you have a selling job to do with the agricultural community."

Too often the science and its applications don't reach the farmer until the problem has become serious. Farmers need to be ahead of the curve, Glock said. "It's a lot cheaper to prevent something than to cure it."

Research recommendations also should include input from farmers and ranchers to ensure wider adoption of technologies, especially practices and policies. "If you want farmers to adopt new practices, you've got to show them how it's going to improve their bottom line. They may not like the idea because they've never done it that way before, but if it's going to make them money they'll give it a good shot," Glock said.

Recommended research needs

- Develop more accurate, longer-term predictions for precipitation and temperature
- Develop ability to downscale climate forecasts to a river basin or local level
- Gather more comprehensive data on snowfall and rainfall patterns
- Gather more comprehensive data on surface water supply and climate at a basin scale
- Improve groundwater and surface water models
- Develop automated data to populate models
- Increase collaborative research among agencies
- Research on social and cultural changes that will help society adapt to climate change
- Include farmers and ranchers in research efforts to overcome skepticism about climate change and ensure adoption of new technologies, practices and policies

Symposium 2
Biofuels, Water Resources and Climate Change: Solving the Sustainability Puzzle

Panel
Ralph Holzfaster, *Farmer, Holzfaster Farms*
Duane Kristensen, *Senior Vice President of Operations/General Manager, Chief Ethanol Fuels*
Todd Sneller, *Administrator, Nebraska Ethanol Board*
Larry Tieszen, *Project Manager, Land Cover Applications and Global Change Research, USGS Earth Resources Observation Science*

Moderator
Kenneth Cassman, *Director, Nebraska Center for Energy Sciences Research, UNL*

Nebraska is now the second-largest producer of corn ethanol in the U.S. This is largely because of the state's comparative advantages. For one, the state's water resources enable a huge capacity for irrigation – Nebraska ranks second in irrigated crop acres, behind California. Nebraska is the third-largest corn producer in the U.S., with 75 percent of the crop irrigated. The state also produces nearly 5 million acres of soybeans, half of them irrigated. Both provide a large, dependable supply of feedstock for production of ethanol and other biofuels. Nebraska's cattle feeding industry, with more than 4.5 million head on feed, utilizes ethanol byproducts such as distillers grains and enables biorefinery systems to attain high energy efficiency and profitability.

From left: Larry Tieszen, Ken Cassman, Ralph Holzfaster

This powerful nexus of agriculture, water and biofuels is highly vulnerable to changes in climate. The panelists represented a cross-section of these interests, including a manager of the state's longest-operating ethanol plant, a farmer with extensive knowledge of ethanol production, the administrator of the state ethanol board and a project manager from a federal agency charged with tracking land use and its ties to biofuel production and climate change.

The past three years have marked historic shifts in agriculture, said moderator Ken Cassman, UNL professor of agronomy and horticulture and director of the Nebraska Center for Energy Sciences Research. "The world has moved from a time of food surplus to food scarcity; from a 50-year trend of steady, continuously lower food costs to very large food price increases; and from a time when the highest value for crops was as a human food or livestock feed, to a time when their highest value is as a feedstock for energy," he said.

The global population is predicted to reach 9 billion by 2050, a 40 percent increase from today. Many of these people will be much wealthier, and as people become wealthier, they eat better food – including more livestock products, Cassman said. Three kilograms of grain are required to produce each kilogram of livestock product, so it takes much more grain to feed people who eat these products. Wealthier people also use more energy. "The link between agriculture and energy is here to stay, and the implications for biofuels, water and climate change are substantial," Cassman said.

Status of corn ethanol biofuel

Corn ethanol production has become a major industry throughout the Midwest. The panelists expressed concerns about the conflicting information in the media about ethanol and how that shapes public and policymakers' perceptions. A 2004 report published by the Nebraska Department of Agriculture noted that ethanol would continue to be one of the most important economic catalysts in Nebraska's economy into the future and this has held true, said Nebraska Ethanol Board administrator Todd Sneller. He recognized the growing interest in new conversion technologies and alternative feedstocks, such as cellulosic ethanol production from switchgrass. "But the only significant biofuel in production today is corn ethanol, and it will be awhile before this changes," he said.

"The link between agriculture and energy is here to stay and the implications for biofuels, water and climate change are substantial."

Duane Kristensen, vice president of operations for Chief Ethanol Fuels, agreed, saying that corn ethanol is now the most viable renewable fuel and will remain so for 10 to 20 years. Since the Chief ethanol plant opened in 1985, he has observed significant changes in the efficiencies of the ethanol production plant but also in the hybrids and farming technologies that provide feedstock to the industry. Although ethanol is being blamed for high corn and food prices, the global economy affects rising commodity prices. This is especially true with commodities like corn, Kristensen said. The devastation of Australia's wheat crop by drought and a poor wheat crop in Europe have contributed to higher prices, as have other factors.

Ralph Holzfaster, a farmer, irrigation dealer and former employee of the Nebraska Public Power District and the Nebraska Ethanol Board, acknowledged that current ethanol and biofuel technology isn't the long-term solution to decreasing U.S. dependence on oil, but asserted that "it's the best alternative we have data on that's economically viable in a commercial scope." Ethanol plants are an economic boon to rural communities, Holzfaster said, citing the town of Madrid, Neb., where a new $80 million plant employs 40 people and has created 120 ancillary jobs in industries such as trucking. "That plant is the biggest thing since the railroad came through in the 1880s," he said.

There is a critical short-term need for corn ethanol, said Larry Tieszen, project manager for land cover applications and global climate research at the USGS Earth Resources Observation Science (EROS) Data Center. "Corn ethanol is a critical, valuable short-term need – but in the near future, cellulosic ethanol will become important and gasification will come after that," he said. Federal researchers are exploring these areas.

Research also is needed on land use, Tieszen said. USGS-EROS is conducting a new study using its best understanding of economic drivers for land use to project the trajectory for land use change in the northern Great Plains. Demand for corn for ethanol and other uses is driving up prices and causing farmers to convert Conservation Reserve Program land to corn, and corn may be moving into vulnerable grasslands in the Dakotas. The researchers are seeking to determine the optimal uses of land in this large region where the soils and climates differ for biofuel applications of all types, not just corn-based ethanol. "We want to be able to suggest what those optimal uses might be for sustainable land use for biofuels applications," Tieszen said.

Ethanol life-cycle energy use modeling

Each panelist spoke of the urgent need for recent, relevant data for calculating the carbon footprint of corn ethanol and for other renewable energy systems that will follow. Sneller cited the U.S. Environmental Protection Agency's (EPA) responsibility to develop life-cycle assessment models for renewable fuel standards mandated by the 2007 Energy Independence Act. This will involve a complex set of compliance requirements related to the carbon footprint of biofuels in several different categories, from a variety of different feedstocks, as they are produced and used. This is a major change, Sneller said.

"Research has played a significant role in positioning Nebraska as a national leader in biofuels for over three decades," Sneller said. "Research will continue to play a very important role in helping us to quantify and meet these new requirements."

The life-cycle energy use model used by EPA will affect how corn ethanol is perceived by policymakers and the general public, Sneller said. More than 60 percent of the current corn ethanol production capacity comes from ethanol plants that have begun production since January 2005, and that will increase to 75 percent by the end of 2009. Yet the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) model, developed by the U.S. Department of Energy's (DOE) Argonne National Laboratory and which EPA and other federal agencies currently use, is calculated with values for energy generated by older ethanol plants that often use outdated, less efficient processing technology.

"It's important to establish the carbon intensity of the current corn ethanol industry, which is best estimated by the newer, much more efficient ethanol plants," Sneller said. He cited the Biofuel Energy Systems Simulator (BESS) model developed at UNL, which uses default scenarios that utilize updated energy use data, including operating data for the last two years collected from dozens of plants in Nebraska and Iowa. Sneller believes the BESS model is more transparent and more thoroughly documented than the version of GREET currently being used to estimate the carbon intensity of corn ethanol. Research providing current data for these models is essential, Sneller said. "If we don't get this model right, ethanol producers will have a difficult time producing ethanol from corn, and the economic consequences of that are significant."

From Left: Larry Tieszen, Todd Sneller, Duane Kristensen

Research is needed to understand all the possible biofuel opportunities across the network of climate and soil types that characterize Nebraska and the Great Plains.

Tieszen agreed that complete life-cycle analysis of the crop used as a feedstock is critical in quantitatively modeling sustainability of any biofuel. There also is a need to consider carbon credits and how those relate to biofuel production and agriculture. Research is needed to understand all the possible biofuel opportunities across the network of climate and soil types that characterize Nebraska and the rest of the Great Plains.

Water use and ethanol production

Questions about water use by ethanol plants are being expressed by the public and in the media. By far the greatest amount of water use is for corn irrigation, but older ethanol plants can use seven or eight gallons of water to produce one gallon of ethanol. Sneller reported that a recent water audit of a four-year-old ethanol plant in Trenton, Neb., indicated consumptive water use of 2.88 gallons of water per gallon of ethanol, a substantial increase in efficiency. "We are also seeing a real interest on the part of those companies who are trying to do business in states like Nebraska, Kansas and South Dakota in low water use systems, and there's an economic factor associated with that as well," Sneller said.

Cassman summarized the issue. "The question is, essentially, can we both produce corn for ethanol in Nebraska, in the Great Plains, and protect water resources within tolerable limits that people in this room would set? And I think that's really the million-, billion-dollar question. And I think it's solvable, and I think the answers about how to do that come out of the creative thinking of a group like this, and that's what's so exciting about it."

Recommended research needs

- Recent, relevant data and complete life-cycle analysis for quantitatively modeling the sustainability of biofuels
- Determine optimal uses of land for production of all types of biofuel feedstocks in the High Plains region, where soils and climates differ widely
- Increase the efficiency of the corn ethanol production process
- Develop cellulosic ethanol and other second-generation biofuels
- Improve yields for biofuel feedstocks – corn, soybeans and proposed second-generation feedstocks such as switchgrass
- Improve efficiency in consumptive use of water by ethanol plants

Symposium 3
Integrating Crop, Livestock and Irrigation Technologies to Ensure Food Security and Environmental Quality

Panel
Jerry Hatfield, *Director, Soil Tilth Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture*
Don Batie, *President, Batie Cattle Company, and President, Dawson County Farm Bureau*
Jon Holzfaster, *Chairman, Nebraska Corn Board*
Mike Kelly, *Rancher and Member, Sandhills Task Force*

Moderator
Rick Koelsch, *Associate Professor, Biological Systems Engineering, University of Nebraska-Lincoln*

The metropolitan areas of Denver and Omaha sit like bookends for the Platte River Basin and High Plains region. In the 500 miles between these metropolitan areas lies a vast, almost completely rural region where farming and ranching are the mainstays of the economy and the culture. Agriculture is not just the primary industry; it is a way of life. This way of life is very vulnerable to changes in climate.

The perspectives of the people who work and live in this region are crucial to informing research on climate change. They are on the frontlines of climate change, as climate impacts and shapes every facet of their lives. In turn, because agriculture is in the business of sequestering and recycling carbon, the decisions and choices agricultural producers make in managing the natural resources in their care can have an impact on mitigating climate change. Most see themselves as stewards of the land and are motivated to pass their land on to the next generation in the best possible condition. But they also are driven by economics – they can't pass on the land if they can't hold on to it – and that means paying the mortgage every year. Research solutions and recommendations need to work economically for farmers and ranchers if they are expected to adopt them.

From left: Jerry Hatfield, Rick Koelsch

"The agricultural community in Nebraska is the part of our society that is going to be most heavily impacted by climate change, and it is also the important potential contributor to the solution," said panel moderator Rick Koelsch, associate professor of biological systems engineering at UNL.

Three of the panelists represented family farming and ranching operations. They included a fourth-generation farmer, a third-generation cattle rancher and a third-generation farmer. All are active in farm and ranch organizations, including the Farm Bureau, the Nebraska Corn Board and the Nebraska Sandhills Task Force. The fourth panelist brought the perspective of a federal research laboratory and was the chief technical author of the U.S. Climate Change Science Program report *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity*. Panel discussion centered on three main topics: the attitudes of the agricultural community toward climate change; the challenges, opportunities and impacts of climate change for agriculture; and how research can meet the needs of the agricultural community.

Attitudes toward climate change

The participating farmers and ranchers expressed some skepticism about climate change, as they live by the weather every day and have managed extremes and changes over many years. They also are pragmatic. If climate change is happening, plans must be made to adapt to and mitigate the effects.

"We see climate get warmer and colder, get wetter, get drier. How much of these changes are due to long-term climate changes and how much is a short-term cycle? To me, that's yet to be decided," said fourth-generation farmer Don Batie.

Farmers often are blamed for only making short-term decisions, "but I have to pay off the bank every year. I farm for the short term, but I look to the long term and what the consequences are."

Batie emphasized that farmers need to look at both the short- and long-term perspectives. Farmers are often blamed for only making short-term decisions, but decisions have to be made based on what will enable them to survive until the next year. "It may make more sense to do things differently if I was farming 10 or 20 years down the road," he said. "But I have to pay the bank off every year. I farm for the short term, but I look to the long term and what the consequences are."

The panelists agreed that the public and political perception is that climate change is occurring, and the agricultural community must approach the issue accordingly, said third-generation farmer Jon Holzfaster.

Challenges, opportunities and impacts of climate change

In a semi-arid environment like the High Plains where agriculture is heavily dependent on irrigation, potential changes in precipitation and its effects on the water supply are a major challenge and impact of climate change, panelists said. They agreed that Nebraska's greatest advantage in the global economy is having one of the world's largest supplies of fresh groundwater for irrigation.

Drier winters, especially in Wyoming where the snowpack is the most important supply of water, have reduced surface water (irrigation) supplies in Nebraska reservoirs so severely that farmers have had to reduce irrigation use, Batie said. Hydropower and recreational uses also are limited. "We will be changing our irrigation practices. We already have and we will be doing more," he said.

Rising energy costs are another challenge, said third-generation rancher Mike Kelly. Irrigation pumps run on electricity and diesel fuel, and prices for both are increasing. At the same time, higher temperatures and reduced rainfall mean more irrigation and increased costs. Kelly also expressed concern about wind power, acknowledging that it is an important source of renewable energy with high potential in Nebraska, but fearing that large-scale wind farms could alter the pristine nature of the Sand Hills.

Jerry Hatfield from the ARS-USDA Soil Tilth Center emphasized the tremendous strain that uncertainty in seasonal weather is going to place on agriculture. "We haven't seen anything yet in terms of the variability in climate that we can experience," Hatfield said. In addition to variability in the wet/dry cycles, rising temperatures is another change that will have a huge impact on agriculture. Initially, yields of corn and other crops will increase with higher temperatures, but long-term scenarios projecting to 2050 show decreases in crop yields because of the effects of higher temperatures on pollination. Higher temperatures also have a negative impact on livestock, an aspect that has not received much attention yet, Hatfield said.

Rangeland studies have shown that increasing levels of atmospheric carbon dioxide cause forage quality to decline, Hatfield said. This could have a tremendous impact on ranching, as it may take more acres to sustain a cow-calf operation if forage quality decreases.

How should uncertainty about climate change be viewed? How should the overall system be managed? These are the big questions, Hatfield said. In looking at the seasonal variability in the climate, a major issue is the uncertainty and risk it causes – uncertainty in production and risk in terms of how crops are managed.

From left: Jon Holzfaster, Don Batie, Mike Kelly

The farmers and the rancher on the panel said carbon sequestration payments could provide an alternative income source for farmers and ranchers and said it is important for the agricultural community to understand carbon credits and how producers can best participate in generating revenue from this source. Holzfaster pointed out again that economics always play a role. "Many of today's carbon friendly activities haven't been motivated as much by reducing carbon footprints as by an economic motivation that also has created carbon advantages. That needs to be considered," he said.

Research needs of the agriculture community

The panelists agreed that accurate long-term predictions of precipitation and temperature are their greatest needs. "I would like to have an accurate projection of what the weather is going to be like for the next year, the next 10 years. That will help me do my long-term planning," Batie said. Continued research on efficient use of water supplies also is critical, panelists said.

Hatfield emphasized the need to develop and utilize research-based risk management tools that allow producers to make field-scale decisions. Researchers must work with producers to develop farm-level decision systems that take all of the variables into account and develop ways to get useable information back to the producers quickly.

The most common theme from the panel regarding research was summed up by John Holzfaster: "It's important for those of us involved in production agriculture that research be done *with* us as opposed to being done *on* us." Knowledge of the challenges and needs of agricultural producers is critical to designing effective, useful solutions.

Farmers and ranchers are often risk-averse, but many also are early adopters of technology and can bring a wealth of knowledge for framing research questions. Koelsch, the moderator, said, "If you can't evaluate your research against a parameter such as Don Batie's 'I farm for the short term, I plan for the long term,' then your research may not be answering the key questions that will impact the eventual use of the science you're doing."

The audience asked related questions about the best ways to engage ag producers in research and to deliver research information to them.

"I have not met a farmer yet who doesn't appreciate visitors to the farm who ask good questions," Batie said. "Those of you doing research on anything involving agriculture, I highly encourage you to make a number of farm visits." Kelly agreed, pointing out that the Sandhills Task Force has worked with UNL on wildlife research on several ranches and will gladly connect researchers and ranchers.

From left: John Holzfaster, Don Batie, Mike Kelly, Rick Koelsch

Corn and livestock commodity groups are valuable organizations for disseminating research, education and administrative information to producers, Holzfaster said. Most farmers and ranchers also are connected to the Internet and use it to stay informed. "Every progressive farmer that I know is online, and I'll guarantee you that UNL is one of my quick links because I go there all the time to check what the latest findings are, to see what they publish and put online," Batie said.

But all agreed that Cooperative Extension remains the best conduit for research to reach the farm. Every county has an extension educator who knows local farmers and ranchers and is trusted by them.

"In working with the agricultural community, you've got to work through organizations they trust," Koelsch said. "The extension service, the commodity groups are places where trust exists. And building collaboration and dissemination of science through organizations like that is critical to seeing your science implemented."

100 years from now

Generational transfer – the transfer of a farm or ranch to the next generation of the family – was clearly a key issue for the panelists and one that is tightly linked to potential impacts of climate change. All view themselves as stewards of the land and as "premier environmentalists" with the greatest motivation to preserve its health and productivity and recognize the need to prepare for and adapt to potential changes in climate. But generational transfer is not possible without economic survivorship, they said. Batie's family has been farming the same ground since 1872, when his great-grandfather broke the sod. "I'm sure that my great-grandfather would be proud that I'm still farming the same ground that he did. But you know what, he made his decisions based on what he needed to do to survive to the next year. He had to make decisions on how he could pay off his bills and feed his family this year."

Holzfaster agreed, urging scientists to be mindful of what is economically viable and realistic, not only for ag production, but also in terms of impacts on input costs and other economic aspects of production agriculture.

Mike Kelly spoke eloquently about the past 100 years in the fragile Nebraska Sand Hills. "If we look at this tremendous resource over the last 100 years, I think that it is in better shape today than it ever has been. I've had old neighbors tell me and I have read in books that 100 years ago you could track a coyote five miles through the Sand Hills because the grass was so thin. Today, whether it's due to a wetter cycle, or rotational grazing programs or programs that we've worked on with the NRCS (Natural Resources Conservation Service) or the university, definitely today that resource is in better shape. Now, I guess I'm proud of the Nebraska ranchers for taking care of that resource like they have been."

Recommended research needs

- Accurate long-term predictions of precipitation and temperature
- Improve the efficient use of water, especially in irrigation
- Develop research-based risk management tools that enable producers to make field-scale decisions
- Involve agricultural producers in research to ensure effective solutions are designed and will be adopted
- Involve commodity groups and agricultural extension system in dissemination of research results
- Communicate research results in understandable, easily accessible formats

"In working with the agricultural community, you've got to work through organizations they trust."

Symposium 4

Invations and Extinctions as a Consequence of Climate Change

Panel

Mace Hack, *Director, The Nature Conservancy in Nebraska*
Rick Kearney, *Wildlife Program Coordinator, USGS*
Chad Smith, *Director of Natural Resources, Headwaters Corporation*
Scott Taylor, *Nebraska Game and Parks Commission*

Moderator

Craig Allen, *Leader, Nebraska Cooperative Fish and Wildlife Research Unit, USGS/UNL*

Invasions and extinctions are occurring at a rate that is unprecedented in historical time. These phenomena are a kind of biological extreme at each end of the spectrum, and both are responses related to landscape and environmental conditions, which also link to climate change. Research shows that species change their ranges in response to climate change and to general predictable trends, but individual responses seem to be idiosyncratic, said moderator Craig Allen. Because of this, there is a need to explicitly anticipate and think about ecological surprises and the unanticipated consequences of global change. Ecological systems often exhibit nonlinear threshold responses, so systems can change suddenly in response to a slow force such as climate change.

From left: Scott Taylor, Craig Allen, Chad Smith

The Platte River Basin can provide a focal point for the study of invasion and extinction and other effects on species related to changes in climate. The Platte River provides critical habitat for many species, including four threatened and endangered wildlife species: the least tern, piping plover, whooping crane and pallid sturgeon. The shallow riverine wetlands along a narrow 100-mile stretch of the central Platte River provide a crucial stop-over for whooping cranes and more than 500,000 sandhill cranes each spring during their northward migration. Approximately 300,000 shorebirds comprising more than 30 species migrate through the North American Migratory Flyway that transects Nebraska. At the other biological extreme, low water levels in the Platte induced by drought have led to invasive species problems. For example, the common reed *Phragmites australis* is choking the river channels and hindering habitat restoration efforts.

The panelists represented a range of organizations and agencies with interest in the effects of climate change on wildlife species and included a representative of the state agency charged with wildlife management, a director on a $300 million

Platte River project, state director for the largest conservation organization in the U.S. and the wildlife coordinator for a federal agency. Their discussion ranged over three broad areas: the potential effects of climate change and challenges they present; research strategies and programs addressing these challenges; and the tools and information needed for decision-making.

Effects of climate change

"The effects of climate change include increased average global temperatures and variability in temperatures over time, longer growing seasons and an increase in the frequency and duration of droughts," said Rick Kearney, USGS wildlife coordinator. For each of these physical changes in climate there will be consequential ecological effects. Plants that are adapted to particular temperature and moisture conditions will change their range, shifting northward or upslope if they are in the mountains, Kearney said. Wildfires will increase as a result of droughts. All of these factors will cause a fragmentation of habitats – species that were overlapping or in proximity will be pulled apart.

"We're going to see an increased frequency of what I call ecological disconnects," Kearney said. "In this situation, plant, animal and pest species that are more generalist can take advantage of changing circumstances and become invasive species."

A prime example is *Phragmites australis*, the common reed, which is choking the Platte River from Kingsley Dam to below Grand Island, Neb. Low water flows in the Platte caused by seven years of drought and below-normal snowpack in the Rocky Mountains, gave *Phragmites* the advantage it needed. *Phragmites* has so completely changed the landscape, including changes in sediment transport and the way sandbars and islands are built, that the problem must be dealt with before recovery plans for the river can proceed, said Chad Smith of the Headwaters Corporation.

Phragmites australis

These same disconnects can cause plant and animal diseases to increase. As new opportunities emerge, especially as winters become milder and the pathogens or the insects that transmit pathogens survive the winter, plant and animal diseases will increase, Kearney said.

Mace Hack of the Nature Conservancy cited another threat related to climate change – land diversion driven by high crop prices and the conversion of non-crop land to crops. "We're worrying a lot right now about temperature and how it's going to affect species, but the biggest threat to species right now is really land diversion," Hack said. This land diversion isn't happening just in the Amazon; it is occurring in the High Plains where Conservation Reserve Program land is being plowed and planted with corn in response to high prices and the demand for corn as an ethanol feedstock.

The Nebraska Game and Parks Commission is developing a comprehensive wildlife conservation strategy incorporating climate change planning, in response

"We need to develop adaptive management techniques, management techniques which will change over time based on what we learn and not on some historic reference point. That is what we have been doing for many years now – trying to restore what was."

to requirements of a federally funded program for conservation of at-risk species, said Scott Taylor of the Nebraska Game and Parks Commission.

Tools and information needed for decision-making

All of the panelists stressed the need for monitoring. Only through extensive monitoring can the basic information about plants and animals in the ecological communities be gathered, and that data are needed to populate ecological models.

"I think the tool we most need to try to address these future challenges is a really accurate crystal ball at the right level of resolution, at a scale that will be useful for designing resilient systems and habitats that will protect the biological diversity represented on the ecoregional scale," Hack said. "How are we ever going to get the data at the scale we need if we don't have a good monitoring network and the people to do the work?" Taylor agreed, saying there is a critical need for more biologists and botanists to do the monitoring. Kearney said long-term monitoring also is needed to understand what is going on in the environment and to understand the effectiveness of our management actions.

The ability to downscale models to an area as localized as a basin was cited as a need by all of the panelists. Climate models that are appropriate for managers at the regional and local scale are needed so they can be linked to ecological models. "In the Northwest they are starting to get those climate models down to the point where you can see what's going on with salmon and other cold-water fisheries. We're going to have to do the same thing for this part of the world," Smith said.

Research strategies and programs to manage resources

The panelists represent organizations with research programs addressing the issues of extinction, invasion and changes in range, habitat and diversity affected by climate change. An innovative approach for addressing these issues is adaptive management. Adaptive management provides a robust framework for making decisions in the face of uncertainty and for assessing the appropriateness of decisions when social, economic and ecological conditions and scientific data all are changing. Data from experimentation and sustained monitoring of ecological conditions is used to adjust strategies and inform policy choices to achieve sustainable solutions to complex social-ecological problems, such as management of limited water resources.

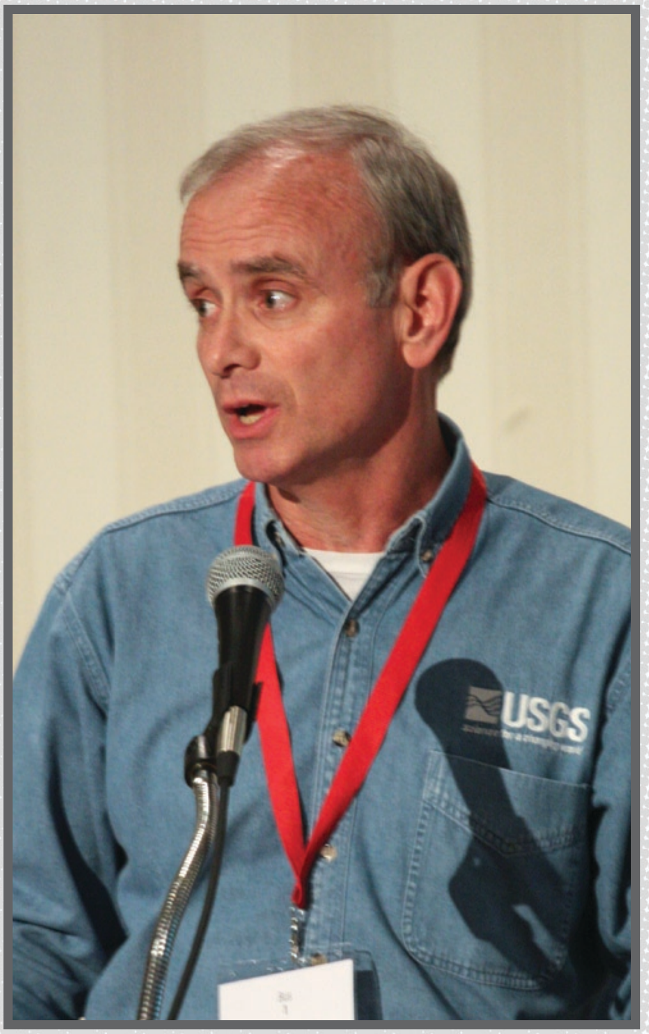
"Adaptive management is perhaps the preferred and best method to help understand the effects of climate change and to do so with experiments where it's okay to fail, where we reduce uncertainties and try to understand the key uncertainties that are present," said moderator Craig Allen, leader of the USGS/UNL Nebraska Cooperative Fish and Wildlife Research Unit. "I'm happy to say that at UNL, with USGS and other partners, we are creating a node of expertise in adaptive management. In my opinion, our key focus should be on maintaining the resilience and adaptive potential of systems, of people and nature."

Kearney agreed. "We need to develop adaptive management techniques, management techniques which will change over time based on what we learn and not on some historic reference point. That is what we have been doing for many years now – trying to restore what was."

Adaptive management also is being used to structure the Platte River Recovery Implementation Program, a long-term $300 million project funded through the federal government and the state governments of Nebraska, Colorado and Wyoming. Major goals of the program are to protect habitats for four endangered and threatened species, increase flows in the Platte River and provide scientific monitoring and research to evaluate benefits of the program.

"The heart of the program is the adaptive management plan," said Smith, director of natural resources for the Headwaters Corporation, which manages the program. "Sensitivity to climate is already having an impact on how we put this adaptive management plan on the ground." The chief strategy being tested with the adaptive management plan for the Platte River program is using water flows in combination with sediment and with some mechanical means to build sandbars and nesting islands in the river and get the endangered species to use them. This plan already is facing challenges from extended drought and reduced water flow in the Platte.

"When the plan was being written in 1997, Lake McConaughy on May 1 before irrigation had a million and a half acre-feet of water to use," Smith said. "In 2007, we had about 600,000 acre-feet to use. So we already don't have as much water as we thought we were going to have, and that's going to force us to adapt our adaptive management plan."



Rick Kearney

The Nature Conservancy's mission is to preserve the plants and animals and natural communities that make up the diversity of life on the planet by protecting the lands and the waters they need to survive. The Conservancy's focus is on natural communities, rather than species. The organization has attributes that position it to study climate change effectively, Hack said. The research is science-based and community-based and always begins with an ecoregional approach, so scientists are working at a scale that is amenable to ecological changes likely to occur. They work at multiple scales, from 100- to 200-acre preserves, in multiple ecoregions and even globally. "We're going to need to work at multiple scales if we're going to address climate change in an effective manner on this planet," Hack said.

The Conservancy also has a strong ethic of being a single organization, although it has separate organizations statewide, nationally and globally, including in 38 countries. "The political boundaries of states and regions don't constrain collaboration, and I think that's a natural framework for the type of collaboration that you all are building here today," Hack said.

USGS is developing a national global warming and wildlife science center in partnership with federal agencies, state agencies, the academic community, industry and the public. Kearney said this initiative was developed by several nongovernmental organizations to urge the federal government to examine and do more to manage the impacts of climate change on fish and wildlife populations. Planning has just begun on a USGS workshop that will bring together all the groups working with fish and wildlife with the goal of identifying priorities for the center. "This is exciting for all of us to come together because this is bigger than all of us combined. But through cooperation, through collaboration, we can take the first steps toward addressing these issues," Kearney said.

Recommended research needs

- Increased and more extensive monitoring networks to gather needed data on the plants and animals in ecological communities
- Develop sophisticated ecological models based on these data
- Develop climate models at the regional and local scale that can be linked to ecological models
- Develop ability to downscale models to an area as localized as a basin
- Develop adaptive management techniques
- Conduct research at multiple scales in multiple regions
- Train more biologists and botanists to monitor ecological communities
- Emphasize collaborative research

CHAPTER 4 DEVELOPING A RESEARCH FRAMEWORK FOR THE PLATTE RIVER BASIN AND THE HIGH PLAINS

DEVELOPING A RESEARCH FRAMEWORK

The grasslands and farmlands of Nebraska are among the most productive agricultural areas in the world – a level of production made possible by the water resources provided by the Platte River and the High Plains aquifer. These resources also are critical to the survival of habitats important to the diversity of plant life and hundreds of Western Hemisphere migratory bird species, including threatened and endangered species.

Climate change and the accompanying pressures may present a major threat to this critical ecosystem. More informed policy, stewardship and legal decisions are required to balance competing ecological and human socioeconomic demands and to ensure long-term sustainability of the High Plains. Yet a lack of robust, comprehensive scientific data characterizing the groundwater, surface water, land cover and geomorphology, combined with deficiencies in modeling capabilities, impede the accurate forecasting needed for the informed decision-making that will enable society to adapt to climate change.

The 2008 Climate Change Workshop brought together USGS and UNL researchers in breakout groups focused on key topic areas to begin developing a research framework for an integrated, real-time knowledge base and system for monitoring responses to climate change for this region. The breakout groups' charge was to identify focused, long-term research and monitoring questions, taking into consideration the existing USGS and UNL research programs and the issues and challenges raised by the stakeholder panels. Each group developed a plan to address these questions that would include an inventory of existing monitoring and data collection capacities and identifying gaps in infrastructure, expertise and the tools needed to successfully implement the research plan.

The breakout groups addressed the following topics:

Topic 1
Climate Change Past, Present and Future: the Nebraska Sand Hills as a Sentinel System

Topic 2
Impacts of Climate Change on Landscapes, Biodiversity and Natural Resources

Topic 3
Carbon Management: The Interaction Among Agriculture, Energy, Infrastructure and Climate

Topic 4
Climate Effects on Water Availability for Human and Ecological Needs

Breakout group summaries in the following pages include the climate effect and response issues, research and monitoring questions and the suggested "next steps" for the research plan identified for each topic. A list of foundation programs, which are existing research programs collecting data in these areas, can be found in Appendix II.

On the following pages is a list of targeted research questions from the four topic areas and a gap analysis of needs in research infrastructure, expertise and tools for decision-making that cuts across all topics.

Targeted Research Questions

Topic 1
Climate Change Past, Present and Future: the Nebraska Sand Hills as a Sentinel System

- What can be learned from paleoclimate records of the Sand Hills and applied to models of future climate changes? Does the paleo-hydroclimatologic record provide an analog of the landscape response to climate change of the type predicted for the future?
- How and where would landscape changes in the northern High Plains aquifer area, and specifically the Sand Hills, be initiated as atmospheric circulation and climate change? What are the spatial and temporal trajectories?

Topic 2
Impacts of Climate Change on Landscapes, Biodiversity and Natural Resources

- How will climate change affect managed systems, in particular agricultural systems?
- How will climate change alter the hydrology in the Sand Hills and what are the interconnections *between hydrologic* and *ecological* environments in the High Plains (e.g., snowpack, runoff and groundwater-surface water interactions)?
- What are the interconnections (including thresholds and alternative stable states) among the ecological, hydrologic and socioeconomic environments in the High Plains, focusing on those that are resistant to change or open to adaptation in light of historical and cultural contexts?
- What are the other key variables, such as soil structure, temperature, and human and ecological population levels, driving potentially major shifts in the Great Plains?

Breakout group discussions

Topic 3
Carbon Management: The Interaction Among Agriculture, Energy, Infrastructure and Climate

- How much water is needed to sustain food production, fuel production, aquatic organisms/systems and wildlife – currently and with climate change?
- What is a sustainable amount of land use for agriculture and for aquatic organisms/systems and wildlife?
- How will climate change increase or decrease land and water use for crops, range/pasture and livestock production?
- What adaptive management strategies would optimize opportunities for food and fuel production?
- How can we assess the carbon balance and carbon sequestration potential of agriculture and energy industries?

Topic 4
Climate Effects on Water Availability for Human and Ecological Needs

- What is the current understanding of contemporary hydrologic and carbon cycle variability and its controls?
- At what hydrologic thresholds do High Plains ecosystems begin to shift in response to climate change/warming?
- How can regional or basin-scale hydroclimatic models quantify the feedback interactions and their uncertainties?
- How does hydrologic variation due to climate change affect agriculture and other human activities in the Platte River Basin and the High Plains? How do we adapt these activities and sustain them in the long term?
- What are the best indicators, and where are the best locations to monitor water and ecological processes to detect climate impacts and change thresholds?

Cross-cutting research questions

- What are the patterns of variability? Are there precursor signals of abrupt events?
- What are the key variables and thresholds in ecological and hydrological systems?
- Is there a critical subset of data that gives us the widest range of indicators of climate change?
- How can monitoring data be integrated into management strategies?
- What kind of risk management strategies and decision support tools can be developed to help communities adapt to extremes in climate?
- How can adaptive management methods be woven into research plans?

Gap analysis: Cross-cutting needs

In the breakout groups' gap analysis of needs in research infrastructure, expertise and tools for decision-making, many of the needs for each topic area overlapped.

Infrastructure gaps

- Additional eddy covariance monitoring towers at key locations
- Additional monitoring stations at key locations: stream gaging, climate, groundwater level, recharge
- Ecological research/monitoring stations
- Coordinated network for data sharing and synthesis
- Software architecture to couple numeric models
- Broad-scale cyberinfrastructure to support scientific communication across stakeholder communities

Expertise gaps

- Modeling expertise: crop and ecosystem, climate
- Sensor networks
- Informatics (hydroinformatics, climatological informatics)
- Ecological statistician
- Ecophysiologist
- Public policy
- Managed, natural and human systems, applied and basic research
- Biologists for field studies, gathering baseline data

Tools to support decision-making

Development of new tools to support research and decision-making and to disseminate the results of research is essential to developing cost-effective, science-based management and policy decisions. The breakout groups identified the following tools as critical to the research framework.

- Modeling
  - Mathematical and statistical modeling techniques for regionalizing climate predictions and running scenarios, and for up- and down-scaling
  - Models linking field to watershed to regional modeling of crop/pasture/livestock water requirements based on historical and future climates
  - Expanded precision for regional groundwater and surface water models
  - Economic models and water budgets
- Data analysis/management
  - Data integration framework to provide common access to disparate data sets
  - Grid computing tools for high-performance data analysis
  - Real-time data network and data standards
- Web-based decision support tools
  - To provide improved capabilities for real-time, in-season deferred irrigation management
  - To provide broader access to data
  - To support community, stakeholder and policymaker access and education
- Real-time sensors and wireless sensor networks
- Risk analysis tools
- Additional eddy-covariance tower facilities to measure CO_2, NO_2 and other fluxes at the landscape level
- Life-cycle analysis tools to measure greenhouse gas emissions from managed and natural ecosystems

Topic 1

Climate Change Past, Present and Future: the Nebraska Sand Hills as a Sentinel System

The Nebraska Sand Hills is a unique region of grass-stabilized sand dunes lying atop one of the largest aquifers in the world. The Sand Hills comprises more than 19,300 square miles of sand dunes stretching 265 miles across Nebraska. With dunes as tall as 400 feet and up to 20 miles long, the Sand Hills is the largest sand dune formation in the Western Hemisphere and comprises the largest grass-stabilized dune region in the world. The dunes were formed by blowing sand and are now stabilized by vegetation consisting mainly of native grasses.

Beneath the Sand Hills lies the High Plains aquifer, the largest groundwater system in North America and possibly the world, spanning more than 174,000 square miles from South Dakota to Texas. The largest portion of the High Plains aquifer – 67 percent of the water in storage – lies beneath Nebraska, and the Sand Hills serves as a massive system that helps recharge the water in the aquifer.

The fragility and sensitivity of the unique Sand Hills ecosystem makes it an ideal early warning system for monitoring climate change.

The fragility and sensitivity of this unique ecosystem makes it an ideal potential early warning system for monitoring climate change. The presence of stable 400-foot-high sand dunes held in place by a thin layer of soil and vegetation is a strong testimonial to the importance and extent of climate change in this region. UNL research has shown that dunes in the Nebraska Sand Hills have been intermittently active for at least the last 18,000 years. These episodes of dune activity are best interpreted as prolonged hydrologic droughts unprecedented in recorded climate history. Recent research dating dune sand and buried interdune peat deposits revealed that the last major episode of dune activity was about 800 years ago and likely was induced by a shift in the wind patterns that decreased precipitation – an example of the devastating effects of climate change.

An integrated research and monitoring system focused on the sensitive landscape of the Sand Hills and the High Plains aquifer could provide data and predictive models that will enable planning for mitigation and adaptation throughout the High Plains region and similar areas.

Climate effect and response issues

One of the greatest threats to the Sand Hills region is reduced rainfall due to climate change and the resulting drought. The grasses stabilizing the dunes depend on rainfall, which is a scarce commodity even in good times – the average annual precipitation ranges from 23 inches in the east to 17 inches in the west. Because precipitation in the Sand Hills is also a primary recharge source for the northern High Plains aquifer, which in turn feeds the many streams and rivers arising in the Sand Hills, reduced precipitation could dramatically change the ecosystem in the Sand Hills and decrease flows in the Platte River system. A change in atmospheric circulation, as is believed to have occurred 800 years ago, and the resulting reduction in rainfall could cause the dunes to destabilize and move again.

Potential risks and hazards.

- Severe drought resulting from change in atmospheric circulation
- Remobilization of Sand Hills dunes
- Reduced stream flow, changes in hydrology

- Changes in greenhouse gas emissions (CO_2, N_2O, CH_4), affecting vegetation patterns
- Decrease in biodiversity
- Land-surface feedback on regional (global) climate
- Changing disease vector pathways from ecosystems to human health
- Changing economic and lifestyle conditions

Human dynamics. The economy of the Sand Hills depends on cattle ranching. Its 12.75 million acres of rangeland are home to more than 535,500 head of beef cattle. Nebraska ranks second in the U.S. in meat exports, with $666 million; second in cash receipts from cattle and calves, with $6.6 billion; and first in commercial red meat production. Cattle are big business, and they depend on the grass-covered hills and hay meadows of the Sand Hills and the abundant water of the High Plains aquifer. The effects of climate change on this environment will directly impact the people who depend on it for their livelihood. Effects on the human dynamics of the region could include:

- Over-allocated water, resulting in reduced quality, quantity and availability
- Deterioration of habitat for livestock and wildlife
- Depopulation due to economic recession caused by reduced viability of rangeland
- Decrease in air quality, increase in dust storms
- Loss of local, national and global food source
- Increase in pests and disease due to climate warming

Public policy and adaptive governance. Science-based policies can help government address the economic, environmental and health impacts of climate change with public policies. Critical issues to be addressed include:

- Economic impacts – tax base, reduced incomes, public utilities, transportation, health implications
- Land-use practices regulation
- Incorporating data from hydrogeologic models into decisions on management policies (water quality and quantity)
- Farm bill programs to offer technical assistance (USDA Natural Resources Conservation Service)
- Protection of endangered species

Touring the Sand Hills

Research and monitoring questions

The critical research and monitoring questions for the Sand Hills center on what can be learned from paleoclimate records and applied to models of future climate changes; monitoring of greenhouse gasses; and studying landscape changes under a changing climate.

a) What are the sinks and sources of carbon dioxide, nitrous oxide, methane and water? What are the controlling factors at different time and spatial scales?

b) How and where would landscape changes in the northern High Plains aquifer area, and specifically the Sand Hills, be initiated as atmospheric circulation and climate change? What are the spatial and temporal trajectories?

- Is the response to an abrupt change the same as the response to a gradual change of the same magnitude?
- Given model predictions, does the paleo-hydroclimatologic record provide an analog of the landscape response to climate change of the type predicted for the future?
- What are the patterns of variability or precursor signals of abrupt events?
- What is the nature of climate variability under different mean conditions? (e.g., How does drought vary under warm conditions versus cool conditions?)
- What are the drivers of long-term regional climate change?
- How do we mitigate and adapt to changing climate and land-cover conditions?

Research gap analysis

The gaps in research needed to answer the key questions were identified.

a) What are the sinks and sources of carbon dioxide, nitrous oxide, methane and water? What are the controlling factors at different temporal and spatial scales?

- Tower and chamber flux studies to quantify carbon dioxide, nitrous oxide, methane and water fluxes at key locations
- Isotope studies of carbon, nitrogen, oxygen and sulfur in the geologic record
- Detailed process-level studies to determine controlling factors

b) How and where would landscape changes be initiated as climate changes? What are the spatial and temporal trajectories?

- Extension of temporal and spatial coverage of paleontological data to target key intervals and locations
- Inventory of plant communities to understand variation in plant communities, topography and soils to identify areas most sensitive to climate change in the Sand Hills
- Experimental studies to determine vulnerability to drought
- Geophysical surveys to map land cover change in the past
- Climate modeling
- Investigation of the paleohydrologic physical and chemical record

From left: David Pitts, Jeonghan Ko

Developing the research plan

Goal 1: Develop an integrated model of the biogeochemical cycling and fluxes of water, carbon and other critical elements in the atmosphere, at the land surface and in the subsurface of the modern Sand Hills region by developing a state-of-the-art sensor system to monitor critical system components.

Action Steps: Create a conceptual model of critical system elements and take inventory of current monitoring capabilities that are part of USGS, UNL and other government and nongovernmental organizations' research efforts. Identify key gaps in equipment, sensor networks, modeling tools and process-based understanding. Monitor system components, analyze data, refine conceptual models, modify the design and reiterate. Develop sophisticated databases, ecosystem models and visualization tools to convey information to policymakers and public.

Goal 2: Critically evaluate paleoecological and experimental data to understand the resilience of the structure (species composition, biodiversity) and functioning (fluxes of energy, water, carbon, etc.) of the Sand Hills landscape to both the direct and indirect (e.g., changes in fire and other disturbances) impacts of climate change of the magnitude predicted under future climate-change scenarios.

Action Steps:
a) Synthesize existing paleo data (lakes, wetlands, dunes, rivers, groundwater) during key intervals of both rapid and gradual climate change to determine critical gaps in spatial and temporal coverage and to target new key research sites in order to develop an understanding of:

- What are the triggers of past land cover change and landscape destabilization?
- How do drought duration, magnitude and frequency compare in relative importance as drivers of change?
- Are there early warning signals of massive landscape destabilization?
- What are the observed ranges of time necessary for vegetation and landscape recovery, and what are the sequences of change that occur during this process (rates and processes of recovery)?
- What is the spatial footprint of major drought, and how does the spatial pattern of drought evolve through time?
- What are the processes, including global and continental-scale ocean-atmospheric drivers, associated with major drought in the mid-continental interior?

b) Continue long-term experimental studies initiated with UNL's Sand Hills Biocomplexity Project to understand the processes involved in the recovery of stressed ecosystems, including physical, chemical and biological system components and structural and functional attributes of the ecosystem.

c) Integrate state-of-the-art mesoscale climate models nested in general circulation models that predict future climate change in the Sand Hills region with paleoecological and experimental data in a series of iterative steps to identify potential analogs that may exist in past landscape behavior and to improve model performance.

Ultimate goal: Develop an integrated model of the system based on data and observation that couples atmospheric models, land-surface models and sub-surface models and can be used to predict likely scenarios of future response.

Topic 2

Impacts of Climate Change on Landscapes, Biodiversity and Natural Resources

Social, economic and ecological resilience and thresholds

Nebraska is positioned centrally in the United States along the 100th meridian. Biotic elements of northern mixed conifer forests, western dry conifer forests, eastern deciduous forests and grassland ecosystems are all present in Nebraska, creating complex transition areas between ecological communities. Economic and social systems also reflect pronounced latitudinal and longitudinal gradients that affect water availability, water use and which crops and cropping systems are economically viable. Social-ecological systems such as the Sand Hills, characterized by extremely low human population densities, grazing systems and fragile grasslands, and the agricultural ecosystems along the Platte River, characterized by higher population density with more and larger settlements, intensive corn-soybean cropping relying on irrigation and remnant grasslands of high biodiversity, are likely to have very low resilience. That means it is unlikely they will be able to maintain critical structure and function following climate change or other major landscape disturbance. In the case of the Sand Hills, this is due to the unique topography – sand dunes immobilized by grasses. In the Platte River Valley, this is due to the reliance for irrigation on water from fully- or over-appropriated watersheds. In both cases, demographic factors are leading to an aging population, declining rural populations, social fragmentation and absentee landownership.

Sand dune blowout

Climate effect and response issues

Resilience theory has been developed by ecologists over the past three decades to explain the surprising and nonlinear dynamics of complex adaptive systems. Resilience theory is the basis for adaptive management, a management approach developed to address the uncertainty of complex resource systems and is applicable to the challenges managers will face in a changing climate. Climate change could alter rainfall patterns, transpiration rates and temperatures – changes that will be reflected in plant and animal distributions. Complex social and ecological systems are maintained by the interaction of biotic and abiotic elements at critical scales. Changes in climate variables that affect the distribution of plants and animals or cropping systems can push these systems beyond their resilience – past a critical threshold – creating rapid and nonlinear responses to climate change. Anticipating, mitigating and avoiding these thresholds are important to maintain the viability of these systems. Maintaining the resilience of the entire system should be the management goal rather than focusing on maintaining certain variables in a relatively constant state.

Potential risks and hazards. One of the potentially greatest threats from climate change is the unraveling of feedback systems, leading to the crossing of critical thresholds. Some early warning signals of this may include:

- Water scarcity
- Species invasions
- Shifts in species phenology
- Increased frequency and severity of natural hazards (fires, floods, blizzards)

Consequences of the loss of resilience may include:

- Pathogens and other risks to health
- Loss of ecosystem services
- New and emerging disease vectors
- Increased social and ecological uncertainty
- Decreased agricultural production
- Water scarcity
- Human immigration or emigration
- Loss of habitat and species
- Degraded ecosystem aesthetics effects on recreation

Human dynamics. An aging population and limited economic options are challenges in the Platte River Valley and the Sand Hills. The Sand Hills relies largely on a cattle ranching economy, and the Platte River Valley area has evolved from a multispecies cropping system with as many as 14 products produced on a single farm to a system dominated by corn and soybean production and heavily reliant on irrigation. Larger farms are needed to support families, reducing the number of farms and families in the region. Relatively small changes in climate may affect agricultural or ecological viability and profoundly impact the agricultural output and social fabric of an important working landscape. In the High Plains, as in much of the world, rural populations are decreasing while urban and exurban areas continue to grow. Rural populations would be increasingly vulnerable as population reductions contribute to the loss of services such as medical care and transportation.

Public policy and adaptive governance. The dynamics of complex systems under stress from climate change may include large-scale disasters such as disease outbreaks, flood and drought cycles, and damaging storms. These dynamics present problems of uncertainty for managers. Planning and management require some estimation of what will happen, yet our predictive abilities for such complex systems are limited due to their evolving and cross-scale nature, and lack of sufficient monitoring, testing and experimentation on system dynamics across scales.

Adaptive governance is an emerging framework for managing complex environmental issues, exemplified by climate change. It is aimed at integrating science, policy and decision-making in systems that assume and manage for change. A program of adaptive management and flexible policy could help maintain the resilience of systems of people and nature in the face of climate change.

Climate change could alter rainfall patterns, transpiration rates, temperatures and overall climate regimes – changes that will be reflected in plant and animal distributions.

Research and monitoring questions

a) How will climate change affect managed systems?
- What is the potential impact of climate change on agricultural production?
- How can we integrate monitoring data into research and decision-making models?
- Is there a critical subset that gives us the widest range of indicators?

b) How will climate change affect natural systems?
- What do grassland ecosystems provide? How do we monitor ecosystem health?
- How can we integrate monitoring data into research and decision-making models?
- Is there a critical subset that gives us the widest range of indicators?
- What driving processes are likely to be lost or gained, and how will this manifest?

c) How will climate change affect human systems?
- What are the most effective techniques to educate a diverse public?

Broader and synthetic questions:
- Is there a subset of critical ecological and social leading indicators of thresholds?
- How do we enhance and maintain resilience and adaptive capacity of our socio-ecological systems?


Breakout group discussion

- What are the barriers to climate change education?
- What are the important scales to understand and address these concerns – decision scales versus process scales?
- What are the interconnections (including thresholds and alternative stable states) between the ecological, hydrologic and socioeconomic environments in the High Plains, focusing on those that are resistant to change or open to adaptation in light of historical and cultural contexts?
- How do external linkages impact ecological and social systems within the Sand Hills?
- What kind of risk management strategies and decision support tools can be developed to help producers adapt to extremes in climate?

A cross-disciplinary research program will require a coordinated systems approach to determine the components and critical scales responsible for creating resilience and to guide modeling and manipulations. Particular study sites will need to be identified; the Sand Hills is a system of low resilience and relatively little human impact, and the Platte River Valley is a system with heavy human impact, water shortages and complex social economic systems. An effective adaptive management plan will monitor and manipulate each of these systems on multiple scales and assess predictions, feedbacks and sensitivity.

Research gap analysis

The gaps in research needed to answer the key questions were identified. Lack of funding has created severe research gaps in understanding how climate change impacts systems of people and nature. The lack of baselines and poorly designed tools for monitoring complex systems, such as groundwater and surface water, microbe populations, invertebrates and vertebrates, hinder inference. Most current monitoring plans were not designed to address climate change questions. Most programs lack scalability or scaling relationships are unknown, and most lack any type of assessment. The research and monitoring questions listed previously all represent gaps in our knowledge.

Developing the research plan

- Determine the components and critical scales of social-ecological systems resilience to guide modeling and manipulations.
- Identify the study sites.
  - e.g., The Sand Hills as a system of low resilience and relatively little human impact
  - e.g., The Platte River Valley as a system with heavy human impact, water shortages, complex social economic system
- Scenario-based assessments of climate change for the region.
- Monitor on multiple scales.
- Assess predictions, feedback, manipulation modeling and sensitivity.
- Establish a communication and outreach plan.

Topic 3

Carbon Management: The Interaction Among Agriculture, Energy, Infrastructure and Climate

Agriculture, water, energy production and use, infrastructure and climate are tightly interwoven in the highly productive agricultural area in Nebraska fed by the Platte River Basin and the High Plains aquifer. The state is the third-largest producer of corn in the U.S., ranks second in the number of irrigated crop acres (after California) and feeds more than 4.5 million head of cattle each year. It now also supports the largest number of corn ethanol plants in the nation, largely due to the stable irrigated corn yields and proximity to cattle feedlots that utilize byproducts of ethanol production.

The potentially greatest threats from climate change to the sustainability of the region's critically important food- and fuel-producing systems are the risk of decreased water quantity and quality and the potential for rapid and unpredictable temperature changes.

Climate effect and response issues

The potentially greatest threats from climate change to the sustainability of these critically important food- and fuel-producing systems are the risk of decreased water quantity and quality and the potential for rapid and unpredictable changes in temperature. These threats are linked. The upper Platte River flows originate from the Rocky Mountain snowpack and are governed by amounts of snowfall and the timing of snowmelt. The lower Platte River also receives inflows from the system of rivers fed by the High Plains aquifer. The region's agriculture, in particular irrigated agriculture, relies heavily on these water resources. Erratic rainfall patterns, increasing temperatures and concomitant evapotranspiration lead to reduced river flows and increased irrigation that further reduce stream flow and place a high demand on energy resources. Drought and reduced corn production impact biofuel production and costs.

Potential risks and hazards. Inadequate water resources and rapid and unpredictable temperature changes could produce:

- Reduction in crop yield potential and livestock performance
- Decreased ethanol production due to reduced corn yields
- Rising costs of inputs for agriculture and biofuel production, including energy, fertilizer, water, feed and feedstock
- Major land use changes affecting crops and cropping systems, biodiversity and conservation, increased urbanization
- Threats to humans, animals and crops from greater pest pressures

Human dynamics. Climate change also can have potentially severe effects on the human dynamics of this system and cause a ripple effect that could be felt globally. Already the demand for corn for ethanol production is being blamed, in part, for global food shortages. Just as the current food shortages are catalyzed by severe drought in the important grain-growing regions of Australia, decreased corn production in the Platte River Basin due to decreased water supplies and climate change-induced drought would affect global food security. In addition to affecting national and global food security, climate change could affect:

- Social and economic viability of communities throughout the region
- Availability and cost of energy for homes, businesses and farms
- Recreation that relies on natural resources

Public policy and adaptive governance. It is critically important to develop effective communication and engagement with the region's stakeholders and policymakers, particularly farmers, ranchers, ethanol producers, electric utilities, rural communities, natural resource managers and others to determine the research outputs that will be most relevant to them. Stakeholders and policymakers need accurate predictive models that will enable a new kind of decision-making and adaptation to climate change. Increased research, data collection and model development can inform development of user-friendly decision support tools. Development and expansion of governance structures for watershed-based decision-making could provide new models for adapting to climate change.

Research and monitoring questions

a) How much water is needed to sustain food and fuel production?

b) What is a sustainable amount of land use for agriculture (crops, livestock and fuel)?

c) How will climate change affect crop, range and pasture, and livestock performance?

- Improvement = reduction in land and water use
- Deleterious effect = increase in land and water use
- Degree of synchrony between precipitation, snowmelt and plant production

d) What adaptive management strategies would optimize opportunities for food and fuel production?

e) How can we better understand, quantify and predict greenhouse gas emissions from managed and natural ecosystems?

Mark Lagrimini

Research gap analysis

- Linking field to watershed to regional modeling of crop/pasture/livestock water requirements based on historical and future climates
- More accurate long-term weather prediction (one to 10 years)
- Improved capabilities for real-time, in-season deferred irrigation management decision support tools
- Impact of intensification of agriculture on existing farmland versus extension of agriculture to greater areas (including marginal lands) using lower input technology and/or organic agriculture
- Ecosystem services that are synergistic with cropland and rangeland systems (It seems that much of the effort focuses on negative effects.)

Developing the research plan

To understand the interactions among agriculture, water, energy, infrastructure and climate, we need to establish a coordinated research effort evaluating water and land use options for the Platte River Basin and High Plains ecosystem under current and future climate scenarios. This will require:

- Identifying appropriate partners in the public and private sectors
- Understanding the impacts on soil, water quality/quantity and wildlife biodiversity
- Evaluating policy and further developing resource management tools to deal with tradeoffs, challenges and opportunities
- Understanding the impacts of expanded biofuel production systems
- Evaluating agricultural production capability for local and global food/fuel security and for economic development
- Conducting an inventory of the existing monitoring and data collection infrastructure
- Better understanding, quantifying and predicting greenhouse gas emissions from managed and natural ecosystems under current and future climate scenarios
- Identifying and quantifying agricultural systems/practices that mitigate greenhouse gases and are cost-effective
- Developing life-cycle analysis tools that enable us to identify opportunities to monetize agriculture's greenhouse gas mitigation potential and develop supporting policies

Topic 4
Climate Effects on Water Availability for Human and Ecological Needs

The grasslands and agricultural lands of Nebraska, Colorado, South Dakota and Wyoming are among the most productive agricultural areas in the world – a level of production made possible by a wealth of water resources. Beneath Nebraska lies the majority of the High Plains aquifer, the largest groundwater system in North America. The Platte River system transects the state and its watershed spans large portions of Nebraska, Colorado and Wyoming. The river is fed by snowmelt from the Rocky Mountains and tributaries arising from the High Plains aquifer. These interrelated water systems sustain a major agricultural economy, native grasslands, important river ecosystems, thousands of acres of lakes and wetlands, and the North American Central Flyway, which is vital to the survival of a majority of Western Hemisphere waterfowl, including many threatened and endangered species. The Nebraska Sand Hills, the largest stationary sand dune area in the Western Hemisphere and a climatically sensitive landscape, also is located in the Platte River Basin. The complex interactions between the aquifer and surface waters are poorly understood, particularly in the context of climate change-induced drought, greater pressures on water resources related to biofuel production and urbanization, and the increasing need to boost agricultural yields to feed a growing world population and meet its energy needs.

Habitat changes in the Platte River Basin affect wildlife, including endangered and threatened species such as the whooping crane, least tern, piping plover and pallid sturgeon.

Climate effect and response issues

The Platte River and its tributaries drain more than 90,000 square miles in Colorado, Nebraska and Wyoming and play a major role in a climatically sensitive region. The recent seven-year drought gives indications of how the ecosystems that the river passes through respond to climate change. Reduced snowmelt from the Rocky Mountains and reduced summer precipitation throughout the region decreased river flows and resulted in increased withdrawals from the river. In turn, the reduced water levels allowed substantial expansion of invasive species, such as common reed (*Phragmites australis*), salt cedar (*Tamarix sp.*) and purple loosestrife (*Lythrum salicaria*), which further decreased river flows. Habitat changes in the river basin affect wildlife, including endangered and threatened species such as the whooping crane, least tern, piping plover, pallid sturgeon, American burying beetle and Salt Creek tiger beetle. Irrigation and recreation are affected by greatly reduced water availability and by increased demand due to increased biofuel production.

Potential risks and hazards.

- Aquifer water level and mass changes from increased demand and decreased recharge
- Stream depletion from increased demand
- Increased competition between groundwater and surface water users, urban and rural users
- Legal action resulting from increased demand (e.g., Kansas/Nebraska Republican River dispute)
- Increase in extreme hydrologic and climatologic events such as flooding, tornadoes and drought
- Unintended consequences of anthropogenic responses (effects from human interventions)

- Feedbacks between land and water use and regional climate pattern
- Economic impacts to agricultural productivity
- Increased waterborne disease from degraded water quality
- Desertification
- Change in species composition, including expansion of invasive species and extinction of sensitive species
- Sediment flux changes in response to climate changes

Human dynamics.
- Population shifts due to economic failure, infrastructure damage from floods, and desertification
- Effects on human health resulting from degraded water and air quality, heat stress and changing species composition that introduces disease vectors
- Effects on ecosystem health that reduce quality of life and recreation
- Economic effects on agriculture, industry, cost and availability of energy, cost of living and transportation

Public policy and adaptive governance. The area of water availability is one where the effects of climate-induced change have already been felt and are challenging decision-makers. Nebraska is at the forefront of developing innovative governance structures and public policies to deal with these issues, such as the Natural Resources Districts system and LB 962, Nebraska's law on the integrated management of surface water and groundwater. Breakout group participants suggested the following areas of need:
- Unified surface water and groundwater management policies between state and local agencies (such as the state Department of Natural Resources and the Natural Resources Districts), between state governments and between water management authorities
- Modernize water law to reflect scientific understanding of the systems
- Review and revise state compacts and agreements that may no longer be valid
- Adopt long-term (multi-decadal) view and planning
- Improve communication of science to policymakers and the public

Research and monitoring questions

a) What is the current understanding of contemporary hydrologic and carbon cycle variability and its controls (similar to an Intergovernmental Panel on Climate Change assessment)?

b) How can regional or basin-scale hydroclimatic models quantify the feedback interactions and their uncertainties?

c) What are the other key variables and thresholds (e.g., soil structure, temperature, human and ecological population levels) driving potentially major shifts in the Platte River Basin and the High Plains?
- What are the ecosystem "indicator species" or cohorts of species whose appearance or disappearance functions as an indicator of tipping points?

d) What are the interconnections (including thresholds and alternative stable states) between the *ecological, hydrologic and socioeconomic* environments in the Platte River Basin and the High Plains, focusing on those that are resistant to change or open to adaptation in light of historical and cultural contexts?
- How do linkages from outside the area impact ecological and social systems within the Sand Hills?

- What kind of risk management strategies and decision support tools can be developed to help producers adapt to extremes in climate?

e) How does hydrologic variation due to climate change affect agriculture and other human activities in the Platte River Basin and High Plains? How do we adapt these activities and what are the thresholds for sustaining them in the long term?

Research gap analysis

- Evapotranspiration (ET) measurement
- Groundwater recharge measurement
- Continuous groundwater level monitoring
- Groundwater/surface water interaction – recharge and discharge relationships
- High resolution hydrogeologic mapping
- Surface water – re-sampling and additional stream gage sites
- Soil moisture – deeper readings, extent and consistency of network
- Wider spatial ecological sampling of streams, lakes and wetlands
- Hydrologic and climatologic record extension

Developing the research plan

a) Refine research objectives
- Complete a comprehensive data network analysis to implement a more extensive, dense, real-time, comprehensive, hourly monitoring network for ET, groundwater, surface water and soil moisture for monitoring indicators of climate change as well as adaptation.
- Identify key indicator species/communities sensitive to variability or indicative of change in relation to hydrologic and climatologic thresholds.
- Define the optimal temporal and spatial scales and sampling regimes.
- Determine early indicators sensitive to variability or indicative of change thresholds.
- Determine the extent to which hydrology in the Sand Hills and the Platte River Basin is indicative of climate change on a more pervasive scale.
- Create a data sharing and integration methodology.
- Define and understand the ecosystem services.
- Delineate the human impacts on ecosystem services.

b) Identify the necessary expertise and project partners and stakeholders.
c) Develop a conceptual model of ecological and socio-economical systems
d) Identify locations at which to establish monitoring sites and experiments.
- Leverage gradients such as precipitation (west to east), temperature (north to south), water balance deficit (southwest to northeast) and population.

e) Identify impacts of climate change on agriculture/human communities.
f) Develop a cyberinfrastructure to support interdisciplinary collaboration and decision support.


The Dismal River

Gap Analysis: Cross-cutting Needs

In the breakout groups' gap analysis of needs in research infrastructure, expertise and tools for decision-making, many of the needs overlap topic areas. They are summarized below.

Infrastructure gaps

- Additional eddy covariance towers at key locations
- Additional monitoring stations at key locations: stream gaging, climate, groundwater level, recharge
- Ecological research stations (similar to Long-Term Ecological Research programs)
- Coordinated network for data sharing and synthesis
- Software architecture to couple numeric models
- Broad-scale cyberinfrastructure to support scientific communication across stakeholder communities

David Swanson at the USGS Woodlands Evapotranspiration Site.

Expertise gaps

- Modeling expertise: crop and ecosystem, climate
- Sensor networks
- Informatics (hydroinformatics, climatological informatics)
- Ecological statistician
- Ecophysiologist
- Public policy: water, natural resource
- Managed, natural and human systems
- Biologists for field studies, gathering baseline data

Tools needed to support decision-making

Development of new tools to support research and decision-making and to disseminate the results of research is essential to developing cost-effective, science-based management and policy decisions. The breakout groups identified the following tools as critical to the research framework.

- Modeling
  - Mathematical and statistical modeling techniques for regionalizing climate predictions and running scenarios, and for up- and down-scaling
  - Models linking field to watershed to regional modeling of crop/pasture/livestock water requirements based on historical and future climates
  - Expanded precision for regional groundwater and surface water models
  - Cross-scale models
- Web-based decision support tools
  - To provide improved capabilities for real-time, in-season deferred irrigation management
  - To support community, stakeholder and policymaker access and education
  - Risk analysis tool for comparing multi-year scenarios for management of water storage and release
- Data analysis/management
  - Data integration framework to provide common access to disparate data sets
  - Grid computing tools for high-performance data analysis

- Real-time data network and data standards
  - Risk analysis tools
  - Life-cycle analysis tools to measure greenhouse gas emissions from managed and natural ecosystems
  - Geospatial information
  - Adaptive management model
- Real-time sensors and wireless sensor networks
- Economic analysis of science-based best management practices and sustainability
- Outreach and demonstration projects to provide information and technical assistance to help producers adapt to climate change

5 CHAPTER PLENARY TALKS

Keynote Address and Conference Charge

Tom Armstrong, Senior Adviser for Global Change Programs, U.S. Geological Survey

I want to thank everybody for being here today, and I really want to extend my gratitude to the University of Nebraska and the people of the state of Nebraska. I used to work for an oil company over in Rock Springs, Wyo., many, many years ago, before I got smart and went to college. Nebraska was always that thing in my rear view mirror when I was going from the East Coast to Wyoming, and I never really got to see the state. I probably fly a lot more than Prem, which is hard to believe. And from the air, you don't get an appreciation for the Nebraska landscape. I have to say in the trip that we took here last fall and then this trip, I've been just absolutely blown away by the landscape, the cultural and the natural diversity of this state.

Tom Armstrong

But along with that diversity comes the issue of sensitivity. In the world we live in today, I can tell you that the Nebraska landscape is a sensitive landscape. I'm not here to try to convince you today that climate change is real. That's for you to decide. But I will tell you my own opinion on this as a scientist and as a manager of the U.S. Climate Change Science Program, a 13-federal-agency consortium that spends about $2.2 billion a year on science and assessing the state of science regarding climate change. For many years this program has really dealt with the issue: Is climate change real or not?

We're beyond that now. Climate change is real. It's no longer a question of who's responsible or is it real. It's a question of what are we going to do about it. What can we do about climate change in order to mitigate the effects of climate change and atmospheric greenhouse gases? And what can we do to adapt to an evolving landscape and waterscape? Those are challenging questions.

A couple of facts that I can tell you are: number one, long-term investment in mitigation strategy is noble. It's something for our children and our children's children. But regardless again of who is to blame for the greenhouse gas concentrations we see in the atmosphere today, whether they are natural or human induced, to change the course of climate, which is like a freight train, will take 40, 50 or 100 years. That means if we were to take measures today to suck CO_2 out of the atmosphere, for example, it will be 40, 50 or even 100 years down the road before we see a positive result in temperature change due to that mitigation strategy.

Again regardless of whether or not you think mitigation is something we need to do – and there are debates about that and there are different opinions – we need to adapt to a changing landscape, and the landscape is already changing in places like Nebraska, Alaska, California, Georgia, the Everglades of Florida. Changes have been detected and they are occurring.

So, I would ask you not to think about or argue whether climate change is real. Instead, think about what effects are we seeing on the landscape that may be related to climate change and what we are going to do about them.

That's my first story. I want to now tell a second story, and that's about what we've done at USGS and the Department of the Interior to handle specific examples of changing climate and its impact on trust resources. For those of you who don't know, I work directly for our director, Mark Myers. We are one Bureau. We are the Science Bureau of the Department of the Interior. There are seven land resource management Bureaus, including the Bureau of Reclamation. Curt Brown, who is here today, is one of our panelists and a member of the Bureau of Reclamation. We have trust resources on one out of every five acres of the United States. We have more landholdings than any other federal agency in this country. The federal land managers are responsible for these trust resources – the natural, physical and biological as well as hydrological resources.

"I would ask you not to think about or argue whether climate change is real. Instead, think about what effects we are seeing on the landscape that may be related to climate change and what we are going to do about them."

Two years ago, the day after Christmas, my director called me. I was new on the job, working as a senior adviser, and he asked me what I knew about polar bears. I said, they're white and have big claws and people think they're cute. He said what about climate change and polar bears? I said, I really don't know a lot about it. He said, well, what we're finding right now is that the Fish and Wildlife Service is proposing to evaluate listing the polar bear as a threatened species. Is there a linkage between climate change and polar bear habitat or polar bear survival?

As we went down this course with scientists from USGS, some of whom are here today, and with scientists from Fish and Wildlife Service, NOAA, National Science Foundation, Canada, across the international community, what we found was this: There was a linkage between future polar bear survival and sea ice because they live about 95 percent of their time on sea ice, hunting, foraging, breeding, denning, surviving. With climate change, the models being run out of NOAA, NCAR, NSF and others are showing that the forecast for sea ice in the future is bad and that there are going to be dramatic declines of sea ice in the Arctic Basin due to global warming.

To cut to the chase, we've developed a set of scientific reports that directly link climate change to sea ice decline, to polar bear habitat and, therefore, to polar bear survival for the future. I won't go into the details of the reports, but I'm sure you've seen some of this on the news lately, that the Fish and Wildlife Service and the Secretary of the Interior have listed the polar bear as a threatened species. Right now, polar bear populations are as high as they've ever been. It seems that everything is going great. It's not the projection of where they've been to where they are today. It's the forecast through the modeling and the science, integrating the modeling and the science of where they're going tomorrow that leads to the listing of the polar bear as a threatened species – the first terrestrial species whose survival has been linked to climate change and its effects.

The moral of the story I want to leave you with is that it took a team of people in academia, the federal sector, the state sector and the private sector, working across modeling communities and polar bear habitat communities, wildlife biologists and remote sensors with satellites. It took a very integrated and well-defined team that shared goals to finally come to a really good set of scientific conclusions that will stand the test of time and, in my opinion, stand the test of litigation. That's why we're here today. It's to develop those kinds of collaborative efforts related to the effects of climate change on the landscape across the academic, federal and state and private communities.

The bottom line with this meeting is that we need your help because we're all in this together. What I'd like to do is just show you a few slides on what we've done at the Department of the Interior. I don't want to sell the Department of the Interior to you. That's not the point of my message. My message is really to talk to you about what we're doing at the Department of the Interior. And regardless of who is responsible for climate change, to talk to you a little bit about what we've done as we've observed these impacts related to climate change and what we're doing about it. I think the kind of model we've developed for the Department of the Interior in moving forward with a plan, a science plan and an action plan, is one that could be embraced by your community and our cooperative community together.

"One thing we do know, in my experience and our scientists' experience, is that decision-making goes on with or without the most up-to-date science."

To start with, a lot of people always ask the question, what is the federal niche in science related to climate change? I put the slide up here to just give you some of the bullets or the highlights of why we come to the table as a federal community. A lot of it has to do with the fact that we have significant scientific capabilities within the federal sector, not just at USGS or the Department of the Interior, but across the entire federal community. We have long-term monitoring records from ice cores in Greenland and Antarctica or alpine glaciers, all the way to remotely sensed information from satellites.

We have a multidisciplinary team. We are biologists, geologists, geographers, hydrologists and social scientists. In some cases, we are managers, we are policymakers, we are lawyers. We are a host of different disciplines all trying to work together for the same outcome. How do we deal with the effects of climate change, not just today but those future effects that we may be able to detect early on before they are catastrophic and we can't do anything significant to mitigate or adapt to them?

We have the capability to assess prehistoric, historic and current climate effects. One of the problems of climate change is that you can't just look at the last 10 years, 100 or even 1,000 years. You've got to go back. You've got to see the whole picture of cycles and patterns and anomalies in order to understand not only what the past was, but whether or not the past is the key to the future. Does the past give us insight into processes that may be occurring today that were analogous to something that occurred 10,000 or 10 million years ago but hasn't occurred since? By having that record of the past, we gain a better perspective of where we're going in the future or what's different about the future compared to the processes of the past. But you have to start with that paleo-record. And we have the capabilities to do so, not just in the academic sector, but in the federal and state sectors, as well.

And we have the ability to integrate these broad arrays and types of information for effective decision-making. I will be the first to tell you as a director of science advisers on global change that we are not doing science for science's sake. We are not. And you are not going to just do a peer-reviewed journal article or write a professional paper and throw it over to the people in this room whom we call stakeholders. We have got to be willing to go the distance to give them the "so what?" of the science and how that "so what?" impacts their issues. And in order to do that, we have to listen to everyone's issues and understand them. Conversely, the onus of responsibility on the stakeholders is to understand our strengths and limitations and to be able to articulate your management and resource issues in a way that the scientists can actually understand, so they can provide you with the right kinds of products that will help enhance your decision-making.

One thing we do know, in my experience and our scientists' experience, is that decision-making goes on with or without the most up-to-date science. So, part of this presentation is also to talk about how we rapidly disseminate and provide you with that information so that it's timely and effective for your near-term decision-making.

The Secretary of the Interior put together a 100-person climate change task force in 2007. I was the chair of the science committee. There were also committees on legal and policy issues and land and water management issues. Across the 100-person task force, we came up with a multitude of resource, management, and legal and policy issues. They were boiled down into these major issues and challenges. Water availability, water quality, increased flood risk, species migration and habitat change, threatened and endangered species, even wildland fire and outbreaks of pest-invasive species and diseases – those transcend animals and people and also impact flora, including agriculture.

These are issues I think resonate with you because I've heard about them over the last two days on our field trip. These major issues come up time and time again, whether it's within the Department of the Interior task force or the state of Nebraska Department of Natural Resources. We need to address the issues with the science and develop a coherent, integrated science plan that addresses them. Whatever the local issue may be, it falls under some of these categories.

Tom Armstrong and conference attendees

I'm not going to go over the science issues in detail, like with the polar bear, which raised some very interesting issues about our laws and our policies. One of the major ones is the National Environmental Policy Act. The other is the Endangered Species Act. They were raised by the legal and policy committee of the DOI climate change task force. I won't go over these in detail, but again they resonate and have intersection with some of the critical species here in Nebraska, like the sandhill cranes or snow geese on the Platte River. But there are a multitude of species beyond those that are endangered or threatened, and we need to deal with them in a critical manner.

So, as I said before, it's not enough just to do science and to do science over five or 10 years and to write a thesis or a journal article and send a copy to Prem or to you. We need to understand that science needs to be provided in an effective medium and in a timely manner. This has really become a new paradigm for management decision-making, not just at USGS but also at the Department of the Interior and the resource management bureaus. How do we take into consideration the dynamic nature of climate change and its impacts? We need data-appropriate scales, from local to regional. Decision-making is not only local. It can be regional. It can be national. But we need scalable information that is seamless in that scalability. We need data and resultant information in a timely manner, as I said before. It's not enough to say it will be here two years from now. I know and you know you're going to make decisions tomorrow with or without that most up-to-date science, with or without this potentially critical information for your decision-making.

One of the major things we realized in putting this task force together is we have resources already on the ground in terms of monitoring and science and adaptive management that we didn't need to build from scratch. And part of the reason we're here today is to recognize that we can't do it alone. We don't have the resources to put together even a DOI-wide climate change system on our own, let alone one for the nation. We need people like you, working with us hand-in-hand, who already have the long-term data records, the scientific studies, the observations and the issues, in order to make this work.

One of the major things we're doing now is looking across the country scientifically at a gap analysis – where are our strengths across academia, across state, local and federal levels? And where are the gaps? Where do we need to apply the resources that we get tomorrow for the problems of today?

As I said before, at DOI one of our major tenets is adaptive management – the recognition that we never necessarily get it right the first time. But whatever our decision-making is and the science that's put into that decision-making, we need to analyze the performance of those decisions and see whether or not we can tweak them or modify the management plan to make it better. And that, in essence, is adaptive management. A big part of what we're doing is trying to provide field management-level input capability. We want managers to be informed of the "so what?" of the science. Some managers may be very technically inclined, others will not be. But we've got to find a level of information that's effective for all field-level people.

We need a flexible and rapidly responsive information framework. It's not enough to say the science has been done. We need to make the investment in those information management systems, in whose development and utilization we all need to share. It's got to work for all of us.

One of the major things you'll hear about later today from my director of the Climate Effects Network, Pete Murdoch, is the development of a national monitoring network for climate effects. We are talking about putting together, in essence, a national climate early warning system – not to tell us about when the signal of climate is changing, but to track – through monitoring and observations – the kinds of changes occurring in the physical and biological systems, and asking whether they are related to climate change. Ultimately, what we want to provide is a national network that will detect early-on changes related to climate change. The reason for this is that up until this point, like with the polar bear and other issues, we've detected the change very late in the game, which makes management, adaptation or mitigation very difficult to do. And in some cases, by the time we detect change out in the field in a nonscientific way, the system may be so far gone that we will not have an effective management solution either for adaptation or mitigation.

The idea is to get out in front of these changes in a proactive way, to understand the physical and biological processes and to come back with an observation network across the country to detect changes early so useful management reactions can occur. Effective ones. And as I said before, rapid information acquisition and dissemination is a top priority.

Pete Murdoch will talk later about our vision and the proposed science needs, and not just for the DOI task force. I think that these science needs transcend anything we do in the field of climate change in understanding the effects of climate on people, wildlife, agriculture, energy; you name it, across the board.

So, ultimately, we have this vision of a truly integrated National Climate Effects Network at a range of time and spatial scales. We want to be able to understand the paleo-history of climate, as I said before, all the way up to forecasting what the future will look like at the local level, the regional level and the national level – a huge challenge but one that's necessary in order to make effective decisions.

We need a scientific team focused on early detection and scientific analysis in support of adaptation or mitigation strategies and that team needs to include people from the states, academia and the federal sector, as well as nonprofits and the private sector. Part of my challenge to you over the next few days is to think about your role in such a team – not just a scientific team but a collaborative team, a community team that can work together in order to provide solutions to some of the major challenges facing us with climate change and its effects.

"We're providing the next generation with some sort of mechanism to at least be able to detect and understand the processes related to climate change and its effects."

We need information dissemination of decision support systems for cost-effective and scientifically supported management and policy decisions. We need to put together a set of tools for decision-makers, not just a set of scientific reports, but a set of solutions or recommendations, things they can use in their toolbox to help them make better decisions. It's information. It's one facet of information, but it's critical information. We want you to have that.

As a scientific agency, we can no longer just pay lip service to decision support. We need to start making significant investments in this way and build the capacity for the next generation to protect and sustain our natural resources through early detection of change. Ultimately, what we're talking about here isn't what's best for us. It's what's best for our children and our children's children. We're providing the next generation with some sort of mechanism to at least be able to detect and understand the processes related to climate change and its effects. And I would state that this is bigger than just climate change. It's what we call global change, the influence of people on the landscape, on biology and on hydrology and geology as well.

So, I want to leave you with just what I thought were a couple of the major elements we saw over the last couple of days. One of the major goals of working together, as Prem described, is to develop stronger ties and a scientific research cooperative between the U.S. Geological Survey and the University of Nebraska. But I want to take that a step further and say we want to develop a closer tie with you on a whole host of issues related to climate change and global change. USGS and the Department of the Interior have a significant capacity here, not just in the state of Nebraska but across the area of the mid-continent, from Denver through Nebraska, Wyoming, Texas and Oklahoma.

Several of the issues we saw, around which we think we can help develop a stronger cooperative agreement or scientific collaboration, relate to management and the interaction between agriculture, energy, infrastructure and climate. One of the realities of climate change is the recognition. There are several voices out there that you hear all the time on the issue of climate change. One voice says we have to do everything to suck all the CO_2 out of the atmosphere tomorrow. And another says you're not going to hurt the economy. The reality of our situation lies somewhere in between.

As a scientist, it's not for me to tell you which voice to listen to, but to provide the scientific information about the feedback and interrelationships among energy, climate and the environment. Regardless of where we want to go with mitigation, the reality is that for the next 30, 40, 50 to 100 years, fossil fuels will be a significant part of our energy portfolio in this country as well as in the developing countries of the globe. That's a reality we have to deal with. How we deal with it is beyond the scope of my job and my pay grade, but scientifically there are realities in that situation we have to address.

We saw climate effects on water availability for human and ecological needs in the Platte River system. The Platte is a beautiful river. I wish I had been here during the time that the sandhill cranes were here. But one of the major paradigm shifts I've seen with water managers and resource managers as a whole is on human consumptive use of water and the recognition that the issue of water availability is not just for people but for ecological services as well. How much water do we need to leave in the system to retain some ecological integrity or capability for resiliency? These are big, big, challenging questions, especially in developing areas like the Everglades of Florida, where the cities of Miami, Fort Lauderdale, Tampa and St. Pete are infringing on that natural ecosystem. We have a responsibility to feed and water people as well as the ecological systems themselves.

A third issue is the impact of climate change on landscapes, biodiversity and natural resources. We saw this yesterday out in the Sand Hills. And David Loope, a geologist at the University of Nebraska, put it well. The Sand Hills look very fertile. They look very vibrant with this vegetative cover on them. I used to work in North Africa–Algeria and Morocco, and the Sand Hills remind me of the Sahara, with a very thin disguise of vegetation. That's what David called it – it's a desert in disguise. And that vegetative cover is extremely sensitive to climate change. A significant or even insignificant change of temperature may mean a significant impact on the Sand Hills region.

At one time in the geologic past, that desert was the second-largest desert behind the Gobi. The Sand Hills is a desert in disguise, and climate will have some sort of impact on it. How significant, I don't know. But science can help us understand that.

These are just a few of the issues we saw along the way that require an integrated multidisciplinary approach, but require science so broad and complex in scale and scope that no single agency can do it alone. No single university has the capacity for long-term monitoring and data required to really understand the long-term as well as the short-term changes and processes. We have to be in this together. We have to work toward a set of big, common goals, sometimes in spite of our shorter-term or local goals and requirements. I know from the people I saw from the University of Nebraska, I know from our people in the U.S. Geological Survey, I know from other folks in the federal sector who I work with on climate change that there is a growing recognition that we are all in this together. It's time to stop talking speculatively about what's going to happen with climate and to provide you decision-makers in this room and beyond this room with real, concise, accurate and objective information about climate change and how it will impact you, our children and our children's children in the future.

I thank you for having me here today and for the whole week. It's been wonderful. I look forward to talking to you individually. I look forward to seeing what happens with the breakout groups, and I look forward to seeing where we go with this in the future. Thank you.

Climate Change Challenges Facing the Electric Industry

Ron Asche, President and CEO, Nebraska Public Power District

I would like to echo Prem Paul's comments. I think the Nebraska Center for Energy Sciences Research is a great partnership between NPPD and the university. I'd like to thank Chancellor Perlman for helping foster that, Vice Chancellor Paul and our center director, Dr. Ken Cassman. Without the support of the NPPD board, that partnership wouldn't have happened. Three of the NPPD board members are here today: Virgil Froehlich from Norfolk, Larry Linstrom from North Platte and Dennis Rasmussen from Lincoln. I'd also like to acknowledge Alan Dostal from NPPD, who is our coordinator between NPPD and the university on our activities and the research center. Thank you.

Ron Asche

Climate change – a real interesting area for the electric utility industry. We're kind of at a crossroads right now of how we go forward in the future with a new issue that appeared on our radar scope only four or five years ago. Climate change is getting much, much discussion in our industry, across the entire country, and we're watching very closely what Congress is doing in that regard.

Our understanding is that Congress is going to debate the Lieberman-Warner climate change bill in the next few weeks, and you can be assured that the electric industry is very, very interested in where that debate goes.

A little background on NPPD. Some of you may not know us very well since a lot of you are here from Lincoln, affiliated with the university and are served by Lincoln Electric System. First of all, Nebraska is an all-public-power state. There are no investor-owned utilities in this state, at least on the electric side of the business. All of the customers we serve are our owners, so that's who we answer to. We don't have shareholders or stockholders, if you will, like the investor-owned utilities. NPPD has about $800 million in revenue on an annual basis and 2,200 employees, and we are capable of generating 3,000 megawatts. I'll talk a little bit in just a moment about the types of generation we have.

We are primarily a wholesale power supplier to rural power districts in the state and municipalities. The City of North Platte, for example, who is hosting this meeting today, is a wholesale customer of NPPD. We sell them the power, and they, in turn, distribute it to all the residential and business people in this community. We supply about half of the total electric requirements in the state. And fortunately we can say that we're one of the lowest-cost states in the country.

We have historically been in the bottom 10 in terms of price, which is where you want to be. And the latest data I saw, which was for the year 2006, indicated Nebraska had the fifth-lowest electric rates in the nation. Some states in the country pay two to three times what we pay here in the state of Nebraska. NPPD understands the importance of having reliable, affordable, low-cost energy for the state of Nebraska and what it does for business. The economy of this state is very important. We understand our relationship with water and the ag industry. That's all very important to NPPD. And our goal, bottom line, is to continue to provide reliable, affordable energy.

A little bit on our fuel mix and its contrast with the rest of the country. On a national basis, about half of the electric energy in the U.S. is produced from coal, and I think we all realize that coal is one of those fuels that is a significant contributor to CO_2 emissions and potential global warming-climate change issues. Nationally, about 22 percent of electric energy comes from natural gas and oil and other fossil fuel. Those sources have about half of the emission rate of coal. The other 29 percent of the nation's energy requirements are provided from a combination of nuclear, hydro, wind, solar, geothermal, all of which are non-emitting resources of electricity.

Contrast that to the state of Nebraska and NPPD more specifically. About 57 percent of our energy is produced from coal in this state. We have a very large coal plant west of North Platte, our Gerald Gentleman Station. That's a 1,365-megawatt coal-fired plant. We also have a 225-megawatt coal plant southwest of Lincoln, our Sheldon Station. We burn very little oil and natural gas today, which is very good, given the price of oil and natural gas. We get 24 percent of our energy from nuclear power, which again is non-emitting. We get about 10 percent from hydro and wind, which also are non-emitting, and a small percentage that we purchase on the market.

"Climate change is getting much, much discussion in our industry across the entire country, and we're watching very closely what Congress is doing in that regard."

Thirty-four percent of our total resource mix is from non-CO_2-emitting resources. But we all know that coal, oil and natural gas are major contributors to CO_2 emissions in this country. When you look at the entire electric industry, production of power from coal and natural gas and oil contributes about 42 percent of the total CO_2 emissions nationally from all sources, transportation being the other major contributor.

In Nebraska, electric power contributes about 48 percent of our CO_2 emissions. You can see transportation is also the other big contributor. And we contribute about 1 percent of the national CO_2 emissions on an annual basis.

As I said, we're following very closely what's going on in Congress regarding CO_2 emissions. A number of bills have been considered and introduced. The one that gets the most discussion is the Lieberman-Warner bill. You can see where our total greenhouse gas emissions are in 2005. It's a little over 7,000 million metric tons a year, including CO_2, methane, fluorocarbons, all of the different types of greenhouse gases. The goal has been set to try and get down to 1990 emission levels by the year 2020. You can see that's quite a dramatic change from what we would project emissions to be if we went forward into the future on a business-as-usual basis, and we don't expect that's going to happen.

Some of these bills have an expectation that by 2050 we would get down to 60 to 80 percent of 1990 emission levels. So, that is a dramatic change this industry might be faced with going forward. And as you saw from the previous charts, coal and fossil fuels play such a significant part of producing energy in this country. It's very difficult to change that overnight. This is something that's going to have to be addressed on a very long-term basis. A number of bills are being considered. Some are cap and trade that will put limits on CO_2 emissions, and eventually you have to get down to some lower level. There has also been talk of having a carbon tax or a greenhouse tax on sources. That has not received as much debate in Congress, apparently because they don't like to add other taxes to already high taxes, so it's easier to hide some of this – if I can use the word "hide" in a cap-and-trade type program – which is a little bit less transparent to the public. But, nevertheless, it has some significant economic costs.

For NPPD, this is what we would look like. The top blue line is where NPPD is today. We put just under 12 million metric tons of CO_2 a year into the atmosphere. If we proceeded on a business-as-usual basis as we had done in the past, we project that by 2027, we would be up to almost 16 million metric tons of CO_2 a year. We've just completed some resource planning, looking at different things that we can do to stem the growth of our CO_2 emissions. At least under reasonable scenarios, we can maintain basically current levels, which is the red line up there. And by 2027, we could still be around 12 million metric tons, even with the continued low growth we would expect to occur in the state of Nebraska, trying to just maintain existing CO_2 levels.

From part of the legislation we expect (at least from the Lieberman-Warner bill) each utility that uses coal would be given some allocation for CO_2 emissions. That's represented in the blue area. Based on our interpretation of that bill, only about 40 percent of our CO_2 emissions would come back with some free allocations. The other 60 percent or so we would have to buy out of the marketplace or somehow find offsets going forward in the future.

So, we have a real challenge. Most of the legislation would give no more free allowances to any utilities by 2030. We'd have to find other offsets or buy emission allowances from other utilities or other sources that were able to reduce their CO_2 emissions. The cost impacts or potential cost impacts are a significant concern for our industry.

The EPA did an analysis of the Lieberman-Warner bill, looking at CO_2 costs starting in 2012, assuming that that bill were passed. They're looking at carbon costs to start at $30 to $40 a ton, escalating up to $90 a ton to $120 a ton by 2030. And that is a fairly significant cost increase. If you translate that into the dollar impact to NPPD, we estimate that in 2012 – if carbon costs are, in fact, in that $30 to $40 a ton range – we would either have to buy or find offsets that would cost us an additional $200 million to $300 million a year in our operation. And that's pretty significant.

So, what does that mean to our electric customers, business, industry, residential, commercial, etc.? We're at these ranges of $30 to $40 a ton or $200 million to $300 million in total for NPPD, which would cause our wholesale electric rates to go up in that 33 to 40 percent range for customers like the city of North Platte and the rural power districts we serve. This is a fairly significant increase. End-use customers, residential, commercial and business would probably see their electric rates go up 20 to 25 percent. Again, a fairly significant increase, and that's why there is so much attention on this particular issue in our industry today.

Our big question within the industry is what we can do going forward. The paradigm has changed. In the past, when we looked at generation resource planning, coal was kind of the de facto source of new generation. Part of that was driven by the oil embargo back in the 1970s, when we were going to get away from reliance upon the foreign sources, even for electric production. Then in 1978, you might recall, the accident at Three Mile Island, the nuclear power plant in Pennsylvania, happened. So, foreign oil and nuclear plants went off the table at that point in time back in the '70s, and coal became the primary de facto source of new generation, along with natural gas. Both of those are fossil fuels that obviously emit CO_2. Now the paradigm has changed, and CO_2 emissions are a concern because of climate change regulations.

What do we do going forward in the future? With nuclear still a challenge, with coal now being a challenge, how do we meet our future power supply requirements and our future load in this country? The industry supports the Electric Power Research Institute (EPRI), the research arm of our industry. They have done a lot of analysis of the implications of CO_2 restrictions and operating in a carbon-constrained world or economy. They have found there's no single silver bullet out there to address our issues. They have found it's going to take a multiple approach to solving this issue from the electric power standpoint. It's going to take end-use energy efficiency programs. It's going to take more renewable energy programs.

"What do we do going forward in the future? With nuclear still a challenge, with coal now being a challenge, how do we meet our future power supply requirements and our future load in this country?"

We need to probably resurrect the nuclear industry in this country, which has been dormant in terms of new construction for the last 20 to 30 years. We need new technology in both types of power plants. It's hard to walk away from a power source such as coal that is abundantly available in this country, in both the eastern and western parts of the country, particularly the Wyoming area. We need technology on CO_2 storage and capture. We need new technology for vehicles, plug-in hybrids. We need to look at distributed energy resources as well.

EPRI's so-called "PRISM" analysis (from the colorful appearance of the graphical results) takes off on where we were with CO_2 emissions in 1990 and what it would look like going forward into the future under the business-as-usual case. You can see the dramatic growth in that. It would take multiple approaches to get emissions down to the 1990 level by 2030. The blue part of that prism is additional energy efficiency that would need to be achieved. The green part is additional renewable energy. The yellow is new nuclear. Today we have only about 104 nuclear plants in this country. To get that level of reduction, we'd need in the area of 50 to 60 more new nuclear power plants by 2030.

The red is new advanced coal technologies that are much more efficient than existing technologies. Our Gentlemen Station unit, a typical coal plant, today operates at an efficiency in the low 30 percent, meaning that for every Btu of energy you put into it, you only get about a third of that out in the form of electricity. We need to find new ways to get more output for every Btu of input. The orange is carbon capture and storage. That's something we're not doing today. That will probably need to be a big part of our goal of achieving the lower emissions going forward into the future. And I think that's where science is really going to have to help us make that feasible at a fairly cost-effective rate.

Finally, we can do more with plug-in hybrids and distributed energy resources. A number of organizations out there have looked at models different from what EPRI has studied. Each of them has their own little twist as to how much can be done by energy efficiency, how much can be done by renewables, etc. I'm not going to get into the debate of whose models are right. I think the point I would emphasize is that it's going to take a multi-pronged approach in our industry to achieve CO_2 reductions in the future if we're going to get away from our historical business-as-usual.

I get an opportunity in my business to go out and talk with other utility executives across the country. They are all concerned about how we are going to meet our future power supply requirements across the nation, particularly during the next five to 10 years. It's going to take longer than that to develop new nuclear power generation in this country. Most of the coal plants that have been talked about have been deferred or canceled. How do we fill that void? That is a real concern. Some utility executives are predicting that certain parts of the country, within five to 10 years, are going to start seeing significant numbers of brownouts, potentially even blackouts.

Trying to meet the challenge is not going to come without some impact on cost of electricity. In some scenarios, we can see that electric costs here in Nebraska could triple from where they are today. On average, our electric rates here in the state are around 6 cents a kilowatt-hour for most customers. Under some scenarios, we can see that go up to 15 to 18 cents a kilowatt hour or more. Some of the areas of the country are already there. Our concern is, what impact does that have on our economy in this state and how do we address that and try and keep the energy supply reliable and affordable at the same time?

Long term, we need to slow, stop and then reverse the amount of greenhouse gas emissions. It's not unlike driving your car down the highway at 60 miles an hour, heading north and then suddenly determining that you need to be going south instead. You can't change directions immediately. You've first got to slow down, then you've got to stop, and then you can go in reverse and get back to going to where you want to go. And that's the challenge we see in our industry.

There are no silver bullets out there that are going to cause us to be able to reverse what we've done overnight. It's going to take time to do that. As I indicated, science is going to have to play a key role in this whole effort, including new technologies that we haven't seen before, particularly for carbon capture and storage. Basin Electric Cooperative in North Dakota has a coal gasification plant where they're taking coal and converting it to synthetic gas. In the process, they're capturing the CO_2 and then transporting it via pipeline to oil fields to enhance oil recovery from the earth.

Some of you might have seen recently in the *Omaha World-Herald* a month or two ago about a Nebraska company that has announced a coal gasification plant, or at least is proposing one, in Texas. A coal gasification plant converts coal to synthetic gas and, in that process, captures CO_2 and again uses it for enhanced oil recovery in the oil fields in Texas. Unfortunately, with all the CO_2 emissions we have and all the coal-fired plants, there are not enough oil fields out there to handle all of the CO_2. So, you really get into a question of what do we do with it once we capture it, if we can capture it?

A lot of work needs to be done. To do that, we expect there would have to be a national pipeline system not unlike the natural gas pipeline system. Once you capture that CO_2, you've got to get it someplace where you're going to store it, whether it would be in the deep ocean storage areas, deep underground, etc. And that's expected to add significant costs to coal-fired generation. The other thing is that in the process, you lose about a third of the output of your power plant. The process will require mechanical equipment, pumps, compressors, motors and all the other carbon capture equipment that you will have to have. You're going to have less output that you can take out onto the grid. So, you effectively lose about a third of the available capacity and energy you can use to serve your customers.

Storage is probably one of the biggest challenges and really has not been addressed yet in this country from a policy standpoint. It's something we don't expect is going to be easy. I think probably all of you are familiar with NIMBY, "Not in My Backyard." I know NPPD faces it when we want to build a new power plant someplace or build a new transmission line. And I understand people don't want to have a power pole or a power generation facility in or near their backyard. But these are societal needs. The plants and lines have to go someplace. Now a new term has been proposed for CO_2 storage: NUMBY, "Not Under My Backyard."

The question becomes, who owns the CO_2 in the storage facility? Who is responsible for it if it escapes? What happens to it once it is injected? What does it do to the groundwater, for example? Does it contaminate the groundwater? Those are questions I think science is going to have to help us answer. Will the public accept it? I don't know. Contrast the potential storage of CO_2 with the issue of storage of spent nuclear fuel from nuclear power plants. How successful have we been in this country with public acceptance of storing that in a central repository? Yucca Mountain has been talked about for about 20 years, probably. NPPD has sent over $150 million to the Department of Energy to help fund the cost of a central repository for spent nuclear fuel. That's just NPPD. The entire nuclear industry has contributed billions of dollars.


NPPD wind turbines near Ainsworth, Neb.
Photo by Brett Hampton

We do not have any type of either temporary or permanent off-site storage facility yet. It goes back to public acceptance. I see a similar challenge dealing with CO_2 storage – where it can be done and whether the public will accept it.

So, where will our electricity come from in the future? As I indicated, coal has taken the back seat right now with concerns over CO_2 emissions and climate change. Many new plants that have been proposed have either been deferred to the future or taken off the drawing board entirely. Two new coal plants were proposed here recently for northwest Kansas. The state of Kansas denied their air permit because of CO_2 concerns. Those power plants are very much needed by the utility that wanted to build them. A coal plant in northwest Missouri was put on the shelf and deferred. The state of Texas about six or eight months ago canceled eight of the plants that were being planned. Florida Governor Crist said no more coal in Florida. The state of California said no coal plants in California. California won't even allow energy produced from coal in other states to be imported. So, where is the future of coal? That's a real good question.

The future viability of the nuclear industry is still a huge uncertainty. We've got 104 nuclear plants in this country today. A new one hasn't been constructed in the last 20 to 30 years. Quite frankly, we have lost the technical skills and ability to even build nuclear power plants in this country. We don't have the pipeline in many of the universities anymore. We're seeing a little bit of resurgence coming in some areas of the country. But where are we going to get the nuclear engineers we need, the skilled craft people we need to build these plants? It's a real challenge. And then once they're built, will they be accepted? That's another challenge. There are huge risks associated with nuclear.

My predecessor is Bill Fehrman, who now is CEO of MidAmerican Energy Company, which is part of Warren Buffet's conglomerate. I had a chance to visit with Bill in January of this year. He had just completed an effort that took six to eight months looking at a new nuclear power plant for MidAmerican Energy, which has no nuclear resource mix right now. When they got done, they concluded there was too much risk, too much financial uncertainty for them to move forward. And if Warren Buffet's company thinks it's too much risk and too much cost, what does that say for the rest of the industry, particularly for entities like Nebraska Public Power, which certainly are not very big in comparison to Warren Buffet's company? So, there are lots of questions.

The other thing on new nuclear is that this country has lost the manufacturing capability to make most of the major components that are required of nuclear power plants. Those are all outsourced. I was at a nuclear conference in Chicago about three weeks ago. What I heard was that 80 percent of the major pieces of equipment in a nuclear plant will be coming from overseas. A big part of that is the forged steel reactor vessel, for example. We no longer have the capability in this country to make them.

Even though there is an interest in the nuclear industry stepping up and building more nuclear power plants to help address the CO_2 issue, the real challenge is where we are going to get the engineering talent, the management talent, the skilled labor talent and the materials we need to do it. The rest of the world is already moving forward with new nuclear– about 30 nuclear plants are under construction in other parts of the world. If we wanted to start today, we've got to get into the queue with some of the major equipment manufacturers. That's going to take time itself.

And the whole process is very lengthy. It takes about 10 years to build a nuclear plant. It takes about two years just to put together the information for the application we have to submit to the Nuclear Regulatory Commission. Once they get the application, it takes three-and-a-half to four years to review it and to give the go-ahead to start construction. And then construction takes probably five to six years, at a minimum, if everything goes well and no interveners try to stop it. Even under the best case scenario, it will probably take 10 years before new nuclear will be around. I also heard at the industry conference that the first new nuclear plants will be online in 2016 to 2018. And that's still really iffy. Many utilities are reluctant to be the first ones out of the box. They want to let "Mikey do it" first and find out what all the problems are before they commit their resources to it. It's a real issue.

What I'm hearing in the industry is if coal is kind of a no-no and nuclear is a long way away, how are we going to meet our requirements in the interim? I hear three things – more natural gas power generation, more renewable energy generation and more energy efficiency and conservation. The problem there, at least with natural gas, is availability and what might the price be. NPPD built a gas-fired power plant that went online in 2005. At that time, gas was trading about $2 to $3 a million Btu. Today we're $8 or $9 a million for Btu fuel costs out of that plant alone, or 9 to 10 cents a kilowatt hour just for fuel costs alone. And whether gas supply would be available remains another big question.

I haven't found one person in the electric utility industry yet who believes renewables and energy efficiency can solve our whole problem. It will be part of the answer, but it will not be the solution to meeting all of our new low growth going forward in the future or be the sole source to help us reduce CO_2 emissions from our coal plants. It's a real challenge for the industry.

If coal is to remain in the mix – and I think it needs to because we have an abundant supply – we've got to find a way to deal with carbon capture and storage. And if we can't do that, we need to find ways to offset those carbon emissions. That's something we'll be working with the university on and finding ways, particularly here in Nebraska, that we can partner with the agricultural community. What you're doing in your industry can help offset part of the emissions in our industry so we can partner and try to find a solution that will benefit all of us. NPPD recognizes the growing public concern about CO_2 emissions. We're undertaking programs to help at least stabilize our CO_2 emission levels at current levels so they don't grow going forward, focusing more on energy efficiency, doing more renewables, etc., and trying to come up with a strategy that will balance both our customers' needs for low cost and reliable energy and, at the same time, help address the climate change issue. We think there needs to be a balanced approach on that.

"If coal is to remain in the mix … we've got to find a way to deal with carbon capture and storage. We need to find ways to offset those carbon emissions."

Here are some specific things we are doing.

- Sheldon Station is one of our coal plants southwest of Lincoln. It was built back in the 1960s, so it's fairly old technology. We're looking at re-powering Sheldon using new technology, including biomass as a source of fuel rather than coal.

- Our board of directors just recently approved the goal of meeting 10 percent of our energy needs from new renewable energy resources by 2020. We built one major new renewable resource a couple years ago. It's a wind farm up south of Ainsworth. Some of you probably have seen that facility. We just signed agreements with two other private wind project developers for a total of 120 megawatts of wind to be built up near Bloomfield. John Hansen is here. John is representing one of those groups. When those projects come online, they will take our new renewable energy from being about 1 percent of our portfolio to about 2.5 to 3 percent. So, it's moving in that direction. I think our board of directors was very insightful for setting the target out there.

- We've looked at lots of different options, and we're going to continue to update our 20-year resource plan, but we realize that renewables and energy efficiencies will have to be a bigger part of our energy future in a carbon-constrained economy.

- We'll be rolling out the energy efficiency programs later this year or early next year. We already did a major program last fall on compact fluorescent lights. We were able to place about 30,000 CFLs out in our service territory. You're going to see more of that in the future. We're working with the state Energy Office, looking at providing low-interest loans to people to upgrade energy efficiency in their homes and businesses. We're looking at pumped hydro storage facilities that utilize a two-reservoir system, a lower reservoir

"Making significant reductions in CO_2 emissions while providing reliable, affordable energy to our customer base is going to be a huge challenge for us. It's probably one of the biggest challenges our industry has ever faced."

and an upper reservoir. During nighttime hours when the wind is blowing and you can otherwise get lower-cost energy, you pump water up to the upper reservoir, and then during the daytime hours when the energy demand is high and energy prices are high, you can release that water and generate electricity. So, that's a project that we're looking at as well.

- And, of course, we think over the long term, our partnership with UNL through the Nebraska Center for Energy Sciences Research is going to help identify some new opportunities and technologies that we can incorporate in the state to help us be more energy-efficient and help us address the CO_2 issue.

I would just close by saying that making significant reductions in CO_2 emissions while at the same time providing reliable, affordable energy to our customer base is going to be a huge challenge for us. It's probably one of the biggest challenges our industry has ever faced. We're really at a crossroads right now on issues that have never approached this magnitude in the past. New technologies will have to play a role, including new technologies for energy storage. We were looking at compressed air energy storage, pumped hydro storage, new types of batteries. Technology is going to be very important, and I think our partnership with UNL is going to be very beneficial.

The bottom line is that NPPD is going to be doing some things to address climate change and be more environmentally friendly on CO_2 emissions, something that enhances our economy and the state, recognizing that our final obligation is to provide a reliable source of power to our customers at as low a cost as we possibly can. We understand the importance of that for the Nebraska economy and the people who live here.

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Foundation Programs and Existing Assets Related to Climate Change Research

UNL and USGS have built a substantial base of research and monitoring expertise and infrastructure in the Platte River Basin and the High Plains region. The following is a brief listing of some of the existing research and monitoring programs related to climate change science in the region. This list focuses mainly on USGS and UNL programs and is far from complete. Other federal agencies and the state governments of Nebraska, Colorado and Wyoming have numerous programs related to the region and climate change science.

Climate Monitoring/Research

USGS

Earth Resources Observation and Science (EROS) Data Center
- Remote sensing and modeling carbon fluxes
- Carbon biogeochemical modeling
- Assessing carbon stocks and soil attributes

Climate Change Program
Climate Response Network

UNL

Platte River Valley Evapotranspiration project
Sand Hills paleoclimate/paleo-environmental research
- Optically stimulated luminescence dating studies

SandHills Biocomplexity Project
High Plains Regional Climate Center
National Drought Mitigation Center
Carbon Sequestration Project
- Sensing and modeling carbon sequestration in corn and soybeans on a large field-scale

Gudmundsen Sandhills Laboratory carbon dioxide flux studies
GreenLeaf Project Drought Risk Management
Areas of research expertise:
- Climate change and variability
- Climate diagnostics
- Atmospheric convection
- Land-atmosphere interactions
- Boundary layer dynamics
- Mesoscale processes
- Sedimentology
- Paleoclimatology

Other

U.S. climate network weather stations
National Atmospheric Deposition program/National Trends Network (NTN)
National Integrated Drought Information System
National Climatic Data Center
Nebraska Climate Assessment Response Committee
Nebraska Department of Environmental Quality air quality monitoring

Hydrologic Monitoring/Research

USGS

Department of Interior Platte River Recovery Implementation Program
- Cooperative Hydrology Study (COHYST) Model

Department of Interior Cooperative Hydrology Study with Departments of Natural Resources in Nebraska, Colorado and Wyoming
USGS National Water Quality Assessment Program (NAWQA)
- Central Nebraska Basins Study Unit
- South Platte River Study Unit
- High Plains Study Unit
- Dismal River Long-term Integrated Monitoring

Groundwater-surface water modeling
USGS High Plains aquifer study
The Platte River Priority Ecosystem Study
The Cooperative Water Program
Water, Energy and Biogeochemical Budget (WEBB)
High Plains Water-Level Change Project
High Plains Water Availability Study
Office of Ground Water Collection of Basic Records Program
Elkhorn-Loup Groundwater Model
Upper Loup Natural Resources District Hydrogeologic Framework Study
Heliborne electromagnetic and surface geophysical surveys for hydrogeologic framework – Sand Hills, Nebraska Panhandle
Groundwater-level observation network
Streamflow monitoring network

UNL

Water Sciences Laboratory
Water Center
Cooperative Hydrology Study (COHYST) Model
Nebraska Registered Groundwater Wells Database
Nebraska Statewide Test-hole Database
Nebraska Statewide Digital Databases for GIS/Mapping
Groundwater Map Archive
Mapping Mean Annual Recharge to Groundwater in Nebraska
Great Plains Cooperative Ecosystems Unit

Center for Advanced Land Management Information Technologies (CALMIT)
- Remote sensing of water quality

Test-hole drilling for aquifer optimization
Geophysics for hydrological characterization
Water Resources Research Initiative research projects/areas of expertise
- Statewide Groundwater Level Monitoring Program
- Surface water-groundwater interactions
- Groundwater recharge
- Water use in agriculture
- Water quality in Nebraska lakes
- Nebraska water policy
- Water property rights issues
- Instream flow legislation
- Public interest test for water appropriations
- Water economics
- Hydrogeology
- Hydrogeophysics and aquifer hydraulics
- Hydrogeologic modeling
- Platte River geomorphic studies

Other

Nebraska Department of Natural Resources Annual Evaluation of Availability of Hydrologically Connected Water Supplies
Nebraska Department of Natural Resources Stream Gaging Data Bank
23 Natural Resources Districts
- Local government entities of elected officials with broad responsibilities to protect natural resources, especially in protecting and managing groundwater

Nebraska Department of Environmental Quality water quality monitoring
Nebraska Department of Health and Human Services municipal water quality monitoring

Ecosystems Research

USGS

The Platte River Priority Ecosystem Study
Earth Resources Observation and Science (EROS) Data Center
Land Cover Institute
Phenological Characterization
NAWQA stream ecology monitoring

UNL

Center for Advanced Land Management Information Technologies (CALMIT) – remote sensing, land cover mapping
SandHills Biocomplexity Project
Hydrology, remote sensing and thermal heterogeneity in floodplain river ecosystems
Impacts of tree invasion on ecosystem processes
Functional characteristics of grasses, trees and shrubs in the Nebraska Sand Hills
UNL/U.S. Fish and Wildlife Cooperative Research Unit
- Amphibians Monitoring Techniques–Rainwater Basin Region
- Cross-Scale Structure in Ecosystems
- Diversity and Ecological Functions
- Monitoring, Mapping and Risk Assessment for Non-Indigenous Invasive Species in Nebraska
- Resilience in Ecosystems
- Spatial Risk Assessment of Invasive Species Impacts on Native Species in Nebraska

Adaptive Management Training

Other

U.S. Fish and Wildlife Service Platte River Adaptive Recovery Plan
Nebraska Game and Parks Commission Natural Legacy Project

Agricultural Monitoring and Research

UNL

Carbon Sequestration Program
Agricultural systems life-cycle analysis
- Effects of climate and crop/soil management practices on agroecosystems, focused on carbon sequestration, greenhouse gas emissions, nitrogen and energy efficiency, and crop productivity
- Quantifying and simulating the potential for net carbon sequestration in agricultural soils

Biofuel Energy Systems Simulator (BESS) tool
- Web-based tool for life-cycle energy and emissions analysis of corn ethanol biofuel production systems

Annual Nebraska Rural Poll
Ecological intensification project
Conservation practices research
SandHills Biocomplexity Project
- Livestock and range management

Rangeland ecology and grazing research in the Nebraska Sand Hills
Effects of precipitation and groundwater on grassland productivity in the Nebraska Sand Hills

USGS

Earth Resources Observation and Science (EROS) Data Center
- Land Cover Institute

NAWQA Agricultural Chemicals-Sources, Transport and Fate

Other

USDA national resource inventory/Conservation Effects Assessment Project
USDA-ARS local/field monitoring
Natural Resources Conservation Service digital soils property mapping
National Soil Survey
North American Soils Geochemical Landscapes (USGS)


Shashi Verma presents research


Picnic at West Central Research Extension Center


The Nebraska Sand Hills


Gudmundsen Sandhills Laboratory


Senator LeRoy Louden


USGS Dismal River Stream Gaging Station


South Central Agricultural Laboratory


Rick Funston, Senator Tom Hansen


Gwendolyn Bachman


Tom Armstrong, Prem Paul


Gudmundsen Sandhills Laboratory


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Stakeholders meeting


Gudmundsen Sandhills Laboratory


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