PREPARING FOR A CHANGING CLIMATE

The Potential Consequences of Climate Variability and Change

CENTRAL GREAT PLAINS

Compiled by:

Dennis S. Ojima and Jill M. Lackett

Contributions by:

Central Great Plains Steering Committee and Assessment Team, including:

Lenora Bohren, Phyllis Breeze, Radford Byerly, Kathleen Galvin, Luis Garcia, LeRoy Hahn, N. Thompson Hobbs, Martin Kleinschmit, Jill Lackett, Kathleen Miller, Jack Morgan, Dennis Ojima, Robert S. Webb

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ABOUT THIS PUBLICATION

This present assessment of the impacts of climate variability and change stemmed from the original Office of Science and Technology Policy (OSTP)/US Global Change Research Program (USGCRP) scoping workshop held on May 27-29, 1997 at Sylvan Dale Guest Ranch in Loveland, CO. The focus of this current, more detailed assessment is on the central Great Plains, which includes all or part of four states – Wyoming, Nebraska, Colorado, and Kansas. Nebraska and Kansas are included in their totality, and the eastern portion of Wyoming and Colorado are included, excluding the mountain regions. The central Great Plains region is one of nineteen regions and six sectors included in the current U.S. National Assessment of the Potential Consequences of Climate Variability and Change. Although these are the region's strict boundaries, many of the analyses were done for the entire Great Plains, defined as all or part of ten states – Montana, North Dakota, South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas.

Whereas the May 1997 scoping workshop focused on ranching, farming, and wildlife sectors, the current assessment is focused on four sectors critical to the Great Plains' economy, ecosystems, and society – agricultural land use and adaptation (cropping systems), ranching and livestock systems, conservation and natural areas, and water. Preliminary workshops were held with stakeholders involved in each of these four sectors, and then all stakeholders were brought together for a capstone workshop held at Sylvan Dale on March 22-25, 1999 to analyze the results from the assessment, and to discuss possible adaptations or coping strategies to deal with the projected changes.

The structure of all workshops was designed in order to encourage presentations about what is known about climate change on the scientific side, and to identify the potential impacts that these climate changes will have on sectors in the Great Plains. The stresses that were identified and the adaptive strategies to deal with them were evaluated for appropriateness. Further, developing and evaluating plausible coping strategies, taking into consideration risks, perceptions, assessments, and management options, is an important outcome of the process. Following from this, the goal of the human dimensions side of the assessment is informed decision-making by stakeholders in the region. Therefore, a flow of information, flexible policies, knowledge of internal/local constraints, and the knowledge of external constraints are needed to result in appropriate adaptive strategies to a changed climate in the region. It was recognized that stakeholders need to understand the impacts of climate variability and change on their home area before thinking about it globally.

This assessment is mainly a stakeholder-driven assessment, with two-way information flow between private citizens, academics, industry representatives, and governmental representatives. It is organized by a steering committee, but the stakeholders in each sectoral group really directed the analyses performed, and provided plausible coping strategies. This collaboration is what made this assessment a success.

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EXECUTIVE SUMMARY

Introduction

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There are many current stresses for residents of the Great Plains, including climate variability, economic volatility, and market pressures. Climate change is just one additional stress that is increasingly affecting Great Plains residents. Projections of climate change in the region include increased temperatures, mainly minimum temperatures, and increased precipitation in many areas. These changes have the possibility of affecting, either positively or negatively, many sectors in the Great Plains, including agriculture, ranching and livestock, natural systems, and water. The possible alterations in climate patterns (extreme events, trends, and variability in seasonal precipitation and temperatures) in the region due to on-going and projected climate changes will likely add to uncertainty for the social and environmental well-being of the region. If adaptations are considered now in order for the residents to take advantage of opportunities that may arise from the changed climate, or to prepare for vulnerabilities that may occur, the residents of the Great Plains will be better prepared for a change in the future climate. Therefore, "no regrets" plans put in place now to deal with climate changes are seen as win-win situations for stakeholders in the region.

Changes in land use management, climate, and hydrological extremes will impact the manner in which natural resources will be utilized and sustained over time, and these will affect the social well-being and ecosystem integrity of the region. Ecosystem integrity (defined as the relative ability to sustain soil fertility, soil moisture, soil organic matter, and atmospheric feedbacks through regional characteristics of precipitation and temperatures) is affected by changes in land use and other human-related activities. These changes in land use and climate at the regional scale are often quite different from national or continental-scale changes, so that variance in regional land use responses to climate change is expected.

There are four main areas in the design of this assessment.

1) Stakeholder Input

In order to better engage stakeholders in the assessment process and to make the assessment more meaningful to the stakeholders the following was accomplished.

- Identify the critical climate information needed to improve management decisions
- Identify the climate assessment questions that are important to the stakeholders
- Design assessment experiments that will be useful for decision-making in evaluating climate variability, climate change, and land use options

2) Climate Analysis

- Historical and general circulation model (GCM) generated climate data for the region were available for use in the assessment
- Two time frames were considered – the decades of 2025-2034 and 2090-2099

3) Impact Response

- Conduct simulations of ecosystem responses to climate variability and change based on the historical and scenario-derived climates. Possible socio-economic responses were also evaluated, although to a lesser degree.

4) Stakeholder Evaluation

- Evaluate the results of the impact analysis with stakeholders to determine the sectoral significance of the impacts and to determine what coping strategies are available or need to be developed.

The four sectoral focus groups that were addressed in this assessment are: agricultural land use and adaptation (i.e., cropping systems); ranching, rangeland, and livestock; conservation and natural areas; and the cross-cutting sector, water. These sectors were picked because of their importance in the Great Plains.

In addition to focusing on four sectoral groups, this report also addresses four main points that are of concern to the stakeholders in the region. First, climate variability and extreme events concern stakeholders much more than changes in averages. It was stated time and again that it is much easier to adapt and cope with a steady change than with erratic conditions. Second, the adaptability of both human systems and ecosystems are discussed at length. Humans in the Great Plains have proved highly adaptive to perturbations over the years, but there is skepticism of the ability of natural or less-managed systems to adapt quickly to climatic changes. The rate of change, fast versus slow, will undoubtedly influence the rate of adaptation. Third, water is an important concern for all stakeholder groups, including quantity, quality, timing, distribution, and form of precipitation. And fourth, the conservation of soil organic matter, and the positive role this may play in buffering operators from climate change, was discussed at length by many groups. From this also stems the possibility of developing a carbon, or other conservation, credit system.

The possible changes in demographics and economics were also considered when evaluating potential climatic changes and their impacts. Particularly important are the economics of coping with climatic changes. Climate change does not happen in a vacuum, and the social and economic situation of the region will have many implications for the way in which people cope or adapt, and with the speed at which they do so.

Conclusions: Results

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Both GCM model experiments project a continuation of the historical trends seen in Great Plains climate over the last 100 years: increased warming, and for some areas, greater precipitation. Maximum and minimum temperatures rise in both scenarios. Minimum temperature increases are greatest, indicating increased nighttime warming; by the 2090s, the increase is over 7° F (3.9° C). Increases are greatest in the western parts of the Great Plains, particularly along the Front Range of the Rocky Mountains. In general, the Canadian Climate Centre model experiment produced a greater increase in temperature, especially in the winter, than did the Hadley model experiment. Both model experiments showed both increases and decreases in precipitation over the region and the seasons, although there seems to be a slightly wetter trend in the region, especially at 2090. The snow season in the Great Plains is projected to end earlier in the spring, reflecting greater warming in winter and spring.

Regional change in climate variability and extreme events may affect various aspects of agricultural systems and people in the Great Plains. First, changes in winter moisture may impact cool season invasives, the extent of sagebrush and other woody perennials on the range, shallow aquifer recharge, streamflow timing, forage availability and quality, and disease incidence. Second, warmer winters may impact the incidence of pest outbreaks, soil organic matter, community composition, grass, and the invasion of exotics. For example, leafy spurge and Japanese brome may move further south. Third, summer increases in temperature and precipitation may impact hail, tree invasives, and fire management. And last, a change in the frequency and duration of extreme events can lead to the opposing problems of drought and deluge, as well as early fall and late spring snow storms which can bring problems all their own.

In addition to the potential impacts discussed above, there were many other potential impacts of climate change in the Great Plains identified by stakeholders. These possible impacts will directly impact farmers and ranchers in the region. Many identified the modified vulnerability of farm/ranch families to climate and market stresses as an impact. This means there will be winners and losers from climate change, depending on the direction of the change and the adaptations employed. Next, crop and livestock production will be modified. This could include increases or decreases in production, as well as, changes in crops, crop varieties, animal breeds, or species. Further, water use competition will likely be impacted by climate change and variability as will water quality. These impacts will likely have important implications for natural resource management and human settlement patterns.

General results are bulleted below:

- There is a strong likelihood that the Great Plains may be a warmer place in the future. The precipitation pattern in the future is uncertain, with areas of both increased and decreased precipitation in the region. The potential warming and altered precipitation regime could have serious impacts for ecosystems and agriculture in the Great Plains.
- There will be both favorable and unfavorable consequences of changing climate in the future. For example, productivity of crops and grasses in the region may increase due to atmospheric carbon dioxide fertilization, whereas decreased soil moisture may decrease productivity.
- Extreme events, seasonal patterns, and variability are important to consider (more than just changes in means).
- Invasive species and shifting ecosystems will be important to monitor in the future.
- Water resource declines, and competition among water users, may increase in the future due to the pattern of altered precipitation and warming, and the urban development in many areas of the region.
- Not all change will necessarily happen gradually. There will likely be some surprises, or rapid change events.
- There is still much uncertainty about the magnitude of climate change and the impacts of those changes.

Conclusions: Coping Strategies

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The possible impacts identified above may include both opportunities and vulnerabilities, therefore, exploitation or coping strategies to deal with the possible changes were also identified. The resiliency of communities and building sustainability are two main issues that were considered when discussing coping strategies. Stakeholders emphasized that production and conservation need to be equally important for building sustainability in the region. Short-term goals, such as those often addressed by policy and economic considerations, should be formed so that they will advance long-term goals, such as sustainability.

The importance of adaptive management was stressed by the stakeholders as an important coping strategy. It is critically important to learn by doing, and there needs to be constant evaluation of what works and what fails to work in an attempt to lessen the possible negative impacts of climate change, and to take advantage of positive impacts in the region.

Effective coping strategies depend on informing the public and decision makers about the implications of climate change for natural systems, agriculture, and human systems, as well as what the effects of changes to systems mean to the quality of human life. This principle is an overarching concern that is fundamental to the discussions of climate change in the Great Plains. It is also an effective way to educate the general public and decision makers about the related issues involved in the climate change debate.

One general coping strategy that was discussed in all sectoral groups is to develop a decision-support system in order to improve how land in the Great Plains is managed. This tool will help landowners decide how best to use their land for the mutual benefit of their operations and natural systems. This will not be easy, as it will require looking at profitability while considering the critical periods for all species and for different systems of land use. The decisions made will certainly differ by area, and the particular strategy of land use for each area will also vary. This decision-support system must also recognize the dynamic nature of natural systems, and allow for continual evaluation of management decisions as conditions change in order to make necessary alterations to adjust for the desired outcome. If these items are monitored as conditions change, many problems can be avoided at later dates.

Recommendations for coping with climatic changes follow:

- Various coping strategies already exist in the region due to the need to deal with historic events involving climate variability. Farmers and ranchers in the region have proved themselves to be very adaptive historically. In addition, many adaptive management strategies used today are appropriate to deal with the more complex interactions between broader societal goals (urban, conservation, community issues) and greater environmental constraints (water competition, agricultural programs, water and air quality issues).
- Coping or adaptation strategies should be flexible and responsive to changing ecological and social trends.
- The rate of the potential changes are especially important when trying to cope, particularly when a change of management is needed.
- Diversification may be a key to coping with potential climatic changes.
- Community-based adaptive management is important to stakeholders for future planning.
- Decision-making aids for land managers will be extremely important when coping with or adapting to climate change.

Conclusions: Research Needs

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There is still much work to be done to truly understand what may happen in the future under a changed climate, and how humans can adapt to changed conditions. Many things cannot be anticipated, and therefore cannot be planned for, but other things that can be anticipated can be prepared for.

Future research needs identified by this assessment include:

- A synthesis of the current knowledge relevant to climate impacts relating to the Great Plains would be helpful for developing appropriate future research activities. This data needs to include current conditions and stresses in the region.
- Better forecasting and methods to prepare for extreme events will be important in the region.
- Continuing development of climate models is needed for more accurate future climate projections.

- Scientists should strive to better inform stakeholders, decision makers, and the general public about the science and uncertainties involved with climate change.
- Multiple stresses on systems will be important to consider more fully in the future.
- Research on the best methods of diversification under a changed climate will help residents adapt to a changed climate.
- New crops or crop varieties, or different animal breeds or species, will likely need to be developed or researched in order to take advantage of a changed climate.
- Valuation of biological diversity to humans and ecosystems should be considered more carefully in order to prioritize activities meant to slow or adapt to changes.
- Research on carbon sequestration and a possible carbon trading system will likely benefit residents in the Great Plains.

CHAPTER 1:

INTRODUCTION

Introduction

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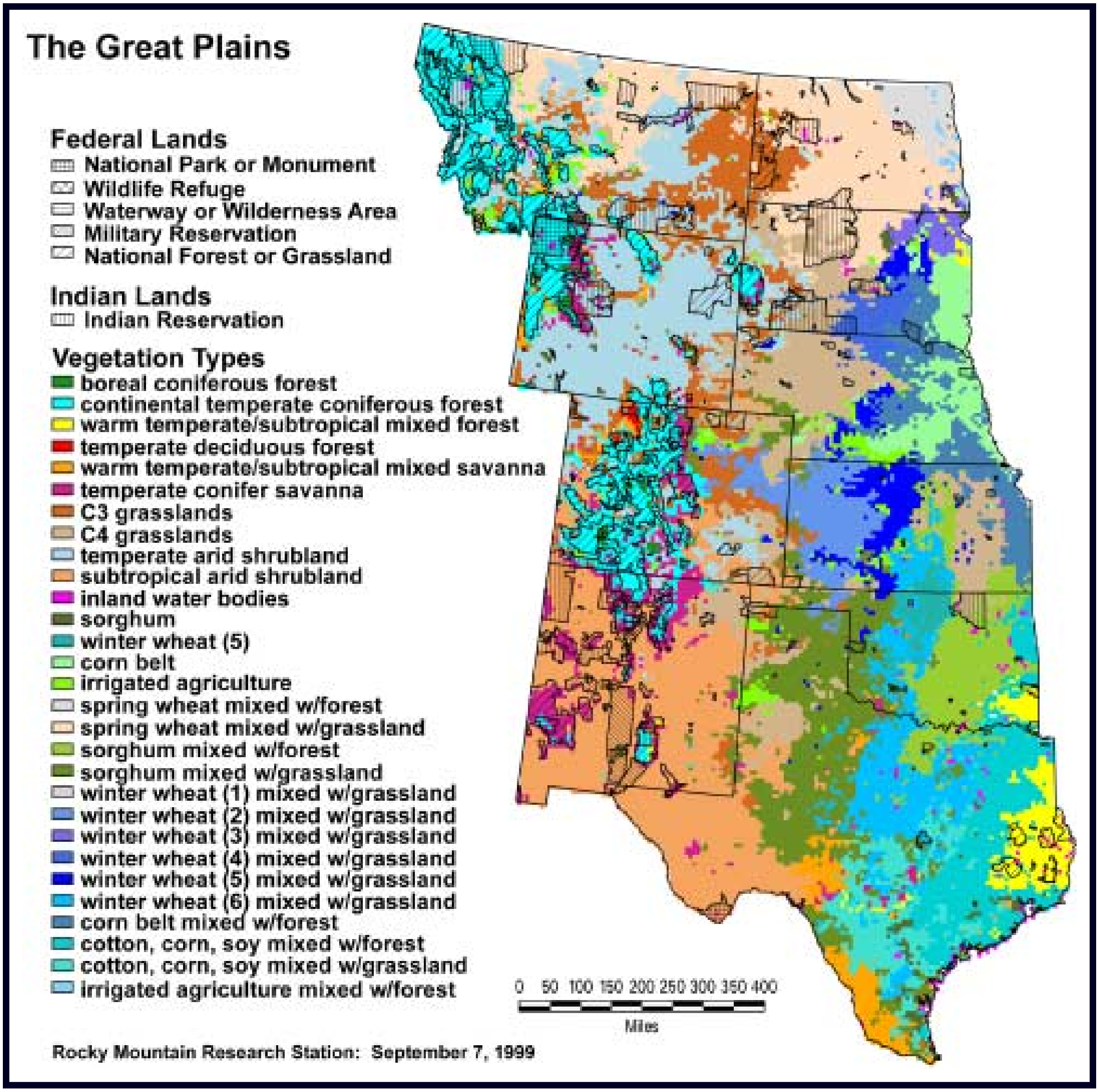
The Great Plains: A Short History

The U.S. Great Plains is a vast temperate semi-arid region once dominated by extensive cool-season and warm-season grassland ecosystems. These natural grassland ecosystems have developed under various natural disturbance regimes, such as frequent grazing, periodic fires, and climate-related events, such as droughts and floods, during the past thousand years. These ecosystems have recovered from these perturbations and they have maintained high levels of fertility and productivity for many centuries. During the past century, many of these grassland areas have been plowed under, and have now been farmed for decades (Fig. 1-1).



Rocky Mountain Research Station: September 7, 1999

Fig. 1-1: Agriculture-related vegetation types (irrigated crops, dryland crops, and grasslands) cover most of the Great Plains region. There are also many federal lands located throughout the Great Plains region. (Modified from Kittel and Ojima landcover maps derived from the Loveland (1991) AVHRR analysis.)

The Great Plains were inhabited by nomadic and semi-nomadic Native American tribes before the mid-1800s when the area was settled by European settlers. The Native Americans in their own way altered the ecosystem dynamics, however, the hunting-gathering societies characterizing the Native American cultures did not extensively alter the flow of water and nutrients in the ecosystems of the Great Plains. The system was in steady-state with the hunter-gather societies for several thousand years. Inhabitants of the Great Plains during the past two centuries have intensified the agricultural land use. Now the flow of water and nutrients in the system are highly constrained and altered. Much of this is due to the settlement patterns and land uses now employed on the Plains.

The Great Plains were relatively slow to develop as an agricultural region because of the aridity of the area. European travelers in the early to mid-1800s called the area the "Great Desert," (Hargreaves 1993) and deemed it uncultivatable and unproductive without irrigation. Settlement of the Great Plains proceeded rapidly after laws such as the Homestead Act of 1862 were passed, which allowed for ownership of 160 acres of land after five years of residency. These policies were terminated in the early 20th century in response to the pervasive abuse of resources on private land. Settlement of the Plains continued, however, and cultivated areas of the Plains grew quickly through the 1920s and slowed as the Rocky Mountains were approached, and as drought and economic troubles became more prevalent. The population in the Great Plains grew rapidly until 1930, when the Dust Bowl period began (mid-1930s). After the 1930s, wheat cultivation rebounded from the effects of the Dust Bowl as war demands for food increased.

From the late 1930s onward, farms and ranches in the Great Plains have been decreasing in number and increasing in size. In 1935, the average farm size was 445 acres (1.8 km^2), but this figure doubled by 1960 and tripled by 1980 (Riebsame 1990). "Great Plains agriculture has tended toward a rather uniform pattern of small-grain farms growing in size and in the level of technological input, rather than in ecological planning or enterprise diversification" (Riebsame 1990:568). Expansion of farms in the Great Plains may be explained by the uncertainty in precipitation, leading to increased acreages in order to increase incomes. By the late 1970s, however, the mechanization of many farming processes had also led to larger farms which are more highly specialized (Baltensperger 1987). This trend of decreasing numbers of farms with increasing acreages is continuing today. Although the number of farms and farmers is decreasing, the amount of land in farms has remained relatively constant over the last 60 years (University of Texas Population Research Center 1998) (Fig. 1-2).

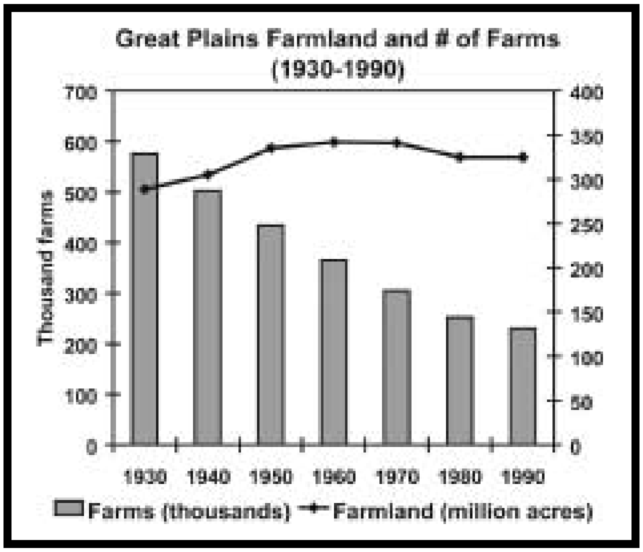


Fig. 1-2: The number of farms (left axis) in the Great Plains has been decreasing over the last 70 years, however, the area in farms (right axis) has remained relatively steady during the same period. (Source: University of Texas Population Research Center 1998)

In the Great Plains environment, variability in weather and economic dynamics result in enhanced uncertainty in land use decisions (Smit et al. 1996). These uncertainties are resulting in changes in the structure of the agricultural sector of the region; for example, in addition to a smaller number of larger farms, farm profits are shrinking, and the rural population is aging and declining (Barkema and Drabenstott 1996, CARD 1993, Licht 1997, Shepard 1986, Stabler and Olfert 1993). Possible alterations in climate patterns (extreme events, trends, and variability in seasonal precipitation and temperatures) in the region due to on-going and projected climate changes adds to uncertainty for the social and environmental well-being of the region. The Great Plains produces much of the nation's food and fiber. The region produces nearly two-thirds of the nation's wheat, more than half its beef, a fifth of its corn, a quarter of its cotton, four-fifths of its grain sorghum, and a sixth of its pork (Duncan et al. 1995). If the agricultural system in the region falters, others around the country and world will undoubtedly be affected.

Changes in land use management, climate, and hydrological extremes will impact the manner in which natural resources will be utilized and sustained over time in the Great Plains and these will affect the social well-being and ecosystem integrity of the region. Ecosystem integrity (defined as the relative ability to sustain soil fertility, soil moisture, soil organic matter, and atmospheric feedbacks through regional characteristics of precipitation and temperatures) is affected by changes in land use and other human-related activities. These changes in land use and climate at the regional scale are often quite different from national or continental-scale changes, so that variance in regional land use responses to climate change are expected. The projected changes in the central Great Plains region are the focus of this regional report.

The Great Plains Today

Current Status

The Great Plains encompass an area of approximately 507,500 sq mi (1,314,500 km^2). The boundaries of the Great Plains are marked on the west by the Rocky Mountains and on the east and south by climatic and vegetative gradients. Generally there is less moisture moving from east to west, and the mean temperature rises from north to south (Fig. 1-3). The Great Plains as a region are restricted by rainfall in the western portion, and by cold winters and short growing seasons in the northern part of the region (USDA 1986). The region is more or less unified by less than 20 inches (500 mm) of rain per year, although yearly rainfall is variable (Blouet and Luebke 1979). In addition to the highly variable rates of precipitation, the Great Plains also have high rates of evaporation, temperature extremes, short growing seasons, strong and persistent winds, and frequent summer hail storms (Hargreaves 1993). These factors make crop and livestock production in the area highly vulnerable, as natural disasters often impede agricultural production. Drought has always been a factor in these grasslands, with the degree and timing controlled by temperature, precipitation, and the ratio of precipitation to potential evapotranspiration (PET) (Parton et al. 1994). Roger Barry (1983) argues that drought is the key climatic parameter of the Great Plains, as it determines the carrying capacity of the region.

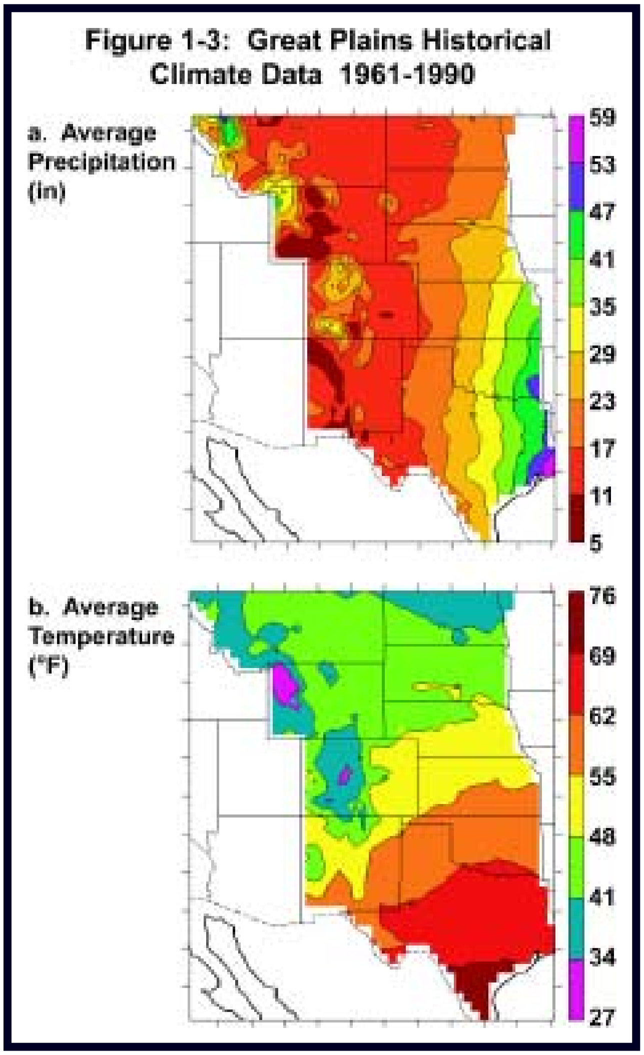


Fig. 1-3: Average historical (1961-1990) precipitation and temperature in the Great Plains region.

Operators in the Great Plains are worried about a variety of factors related to climate variability and change. Climate change is not the most important concern, however, as there are many other stresses in this region now, including market-driven stresses, policy stresses, and social stresses. In fact, many operators in this region are vulnerable due to the declining reward scale for farming and ranching. Many operators operate with a narrow profit margin, and small shifts in climate or markets could drive them out of business, as could an increase in extreme events (e.g., heat waves, drought). There have been record numbers of foreclosures in the region during the past few years, and these farms are often being bought by corporations or large family operations, which is contributing to the trend in the Plains towards fewer numbers of larger farms. This leads to population declines in the region, and the aging of the farm population, as new, young operators are not coming into the region in great numbers. This trend has put pressure on rural areas, leading to a stressed system where rural towns may have problems providing adequate social services for inhabitants due to declining population numbers, tax bases, and rural infrastructure.

The average annual temperature over the last hundred years is about 43° F (6.1° C) in the Northern Plains and 59° F (15° C) in the Southern Plains. Variability is common in the region, with 'average' years often being the exception rather than the rule. In the last century, the Northern and Central Great Plains have warmed about 2° F (1.1° C), whereas no strong trends are evident in the Southern Great Plains. In the last

100 years, the minimum temperatures have increased more than maximum temperatures, and the warming is more pronounced in the winter which has resulted in the snow line moving north. Also in the last century, annual precipitation has increased by 5-20% in South Dakota, Oklahoma, Texas, and in parts of Kansas (Joyce et al. 2001).

A number of recent analyses have demonstrated relationships between equatorial Pacific sea-surface temperatures (e.g., El Niño) and central North American drought (Ting and Wang 1997, Trenberth and Guillemot 1996). More recently, a global analysis of the Palmer Drought Severity Index (PDSI) for the past century shows clear regional patterns of drought and wet conditions that can be correlated with different phases of the El-Niño/Southern Oscillation cycle (Dai et al. 1998). In many regions of the Great Plains, there have been milder and fewer droughts in the past century than in the previous two centuries (Cook et al. 1999). Within the Northern Great Plains (North and South Dakotas), Bunkers et al. (1996) have documented an increase in April to October precipitation in response to El Niño conditions, and a slightly weaker precipitation decrease in May to August precipitation in response to La Niña conditions. They also found colder winter temperatures associated with La Niña conditions, whereas, cooler August to October temperatures were associated with El Niño conditions. Extracting information for the South Platte, a river basin in the central Great Plains region, from a continental scale analysis of climate extremes and El Niño/Southern Oscillation (ENSO) (Wolter et al. 1999), it was found that similar but weaker relationships exist between ENSO and precipitation and between El Niño and August to October temperature, whereas, the La Niña conditions had little impact on winter time temperatures (Wolter et al. 1999).

By virtue of its scarcity, water is a critical resource in the Great Plains. Although the region is characteristically dry, humans have managed to transform the land to overcome this limitation. Because water has been a central component of that transformation, the issue of a continuous, sufficient supply of water is of major concern to the inhabitants. Water supply sources include surface water in rivers, streams and lakes, primarily from snowmelt, shallow and deep aquifers, and rain. The flow of these waters has been altered by humans through diversion, impoundment, and irrigation for urban and agricultural uses. Rainfall is not always sufficient, even with existing surface water impoundment facilities, to support the demand necessary to maintain the agricultural yields experienced today, particularly in the western portion of the Great Plains (Norwood 2000). Considerable supplementation has been through irrigation from aquifers, which makes their depletion a serious concern in some areas of the region because the rate of depletion of these aquifers is often faster than the rate of recharge.

Nearly all freshwater ecosystems in the Great Plains have been modified by human activities and land uses, including the alteration of thermal regimes, habitat destruction resulting from dams, diversions, and channelization, and altered groundwater flow patterns as a result of pumping and erosion. Point and nonpoint source pollution have introduced a wide array of organic chemicals, toxic metals, and fertilizers, such as nitrogen and phosphorous into these aquatic ecosystems. Alteration of vegetation, introduction of nonnative plant and animal species, and over-harvesting of native species have also damaged these aquatic ecosystems.

Considerable water pollution results from fertilizer, pesticide, and waste runoff, as well as from sedimentation. This results in increased salinity, nutrient loading, turbidity, and siltation of streams. Shallow aquifers also suffer from these pollution problems (NRCS 1996). Drinking water quality is reduced as a result of pollution, particularly in small towns where the water supply does not come from municipal treatment systems and where runoff and leaching of agricultural chemicals is common. This decrease in water quality has affected food production, human drinking water supplies, and wildlife habitat.

Some of the other environmental problems in the Great Plains resulting from urban and agricultural practices include erosion, increased alkalinity and reduced carbon storage in soil, increased runoff, and an explosion of weedy species. Erosion can be a problem in both the eastern and western portions of the Great Plains. In the east, water erosion can erode 1 to 3 tons/acre/year, with up to 8 tons/acre/year in some areas. In the west, wind erosion can erode 1 to 8 tons/acre/year, with the highest losses in parts of Colorado and Texas (NRI 1997). Ten percent of the Northern Great Plains landscapes are affected by salinity due to irrigation, with a 10% annual increase due to inefficient irrigation distribution systems, poor on-farm management practices, and inappropriate management of drainage water (NRCS 1996, Riebsame 1990). Salinity refers to a situation where soluble salts left in the soil after the irrigation water evaporates or is transpired impair the soil's productivity for plants. "Tillage pan" from soil compaction is found in half of the cultivated land in the region (Riebsame 1990).

While there have been some improvements in land management practices through conservation measures (e.g., fallow, minimum tillage) to reduce soil loss, increase soil moisture, and stabilize wetlands (Lackett

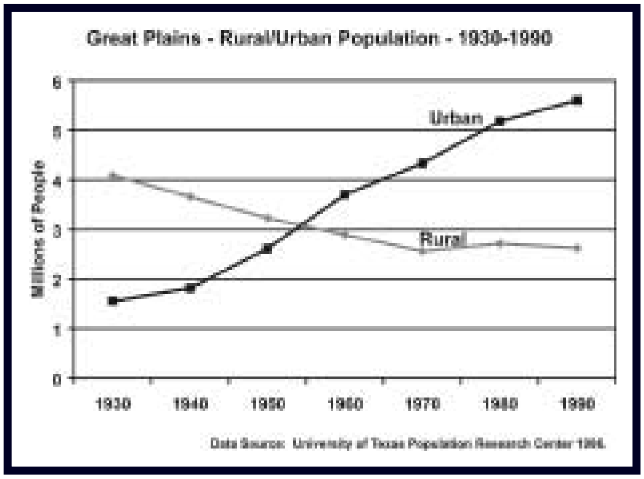


Fig. 1-4: In the last 70 years, the rural population in the Great Plains has declined, while the urban population in the region has climbed steadily.

1998), much of the area was found to be in need of conservation treatment by a 1992 National Resources Inventory study (45% of cropland, 68% of irrigated land, and 62% of rangeland) (NRCS 1996).

Population and Society

In 1997, there were 9 million people (approximately 3.4% of the total U.S. population) living in the US Great Plains, with over half residing in the central Great Plains (4.7 million people). Although the population has been increasing in the region, the growth has not be equitable across counties. Thirty-nine percent of the counties in the Great Plains have had declining populations in the years from 1990 to 1999 (University of Texas Population Research Center 1998), with rural counties much more likely to lose population than those with some urban developments (Duncan et al. 1995). Even though the overall population of the region increased by 16% from 1969 to 1991, less than 20% of this increase was realized outside the urban centers, which are thriving as regional trade and marketing hubs (Albrecht 1993). Recent economic gains in rural counties have been concentrated in a little over 1/3 of these counties, mainly those that are in scenic areas or near urban centers.

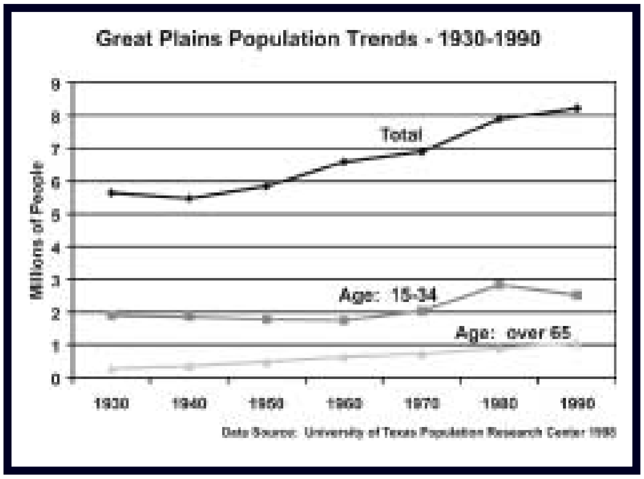


Fig. 1-5: The population in the Great Plains is aging. The number of people who are living in the region who are 65 years old or older has steadily increased over the last 70 years. Likewise, the total population of the region has been increasing, although this growth is most often felt in urban areas, with other areas of the region often losing population. There was a decline between 1980 and 1990 of the number of residents aged 15-34.

Whereas in the 1930s less than 35% of the population of the central Great Plains were urban dwellers, in 1990 over 75% of the residents of the central Great Plains live in urban areas (University of Texas Population Research Center 1998) (Fig. 1-4). The other 25% of the people in the region live in rural areas, where agriculture and ranching are still the dominant land uses. In many of these rural areas, over ten Native American tribes call the Great Plains home today, including the Crow, Sioux, Cheyenne, Arapaho, and Shoshone tribes. These tribes now inhabit several reservations in the region (see Fig. 1-1).

Although the region is highly agricultural in it's rural areas, in 1997 39% of the farm operators designated their occupation as "other," not as "farmer" (50% or more of their work time is not on the farm). The percentage of farmers who designated "other" as their occupation has been increasing; from 1992 to 1997, there was a 14% increase (USDA Census of Agriculture

Table 1-1: Comparison of demographics in the rural and urban counties of the Great Plains and the United States.

	All Great Plains Counties	356 Rural Counties	93 Urban* Counties	United States
Total population (1990)	8,228,535	2,072,917	6,155,618	248,709,873
% of persons 65 and older (1990)	13.9	18.7	12.2	12.6
Per capita income (1998)	25,457	21,125	26,778	27,203
% of persons below poverty level (1995)	13.3	15.9	12.5	13.8

* Counties are identified in University of Texas Population Research Center (1998). We categorize as urban all counties with an urban population of 10,000 or more in 1990.

1992, 1997). This stresses the fact that with declining profit margins on farms, many farmers in the region are having to also work off of the farm in order to make ends meet. Similarly, many spouses are now working off of the farm in areas where there is access to other forms of employment.

Since the time of settlement, the variable and semi-arid climate has been a challenge to people trying to live off the land. Marginal areas have been ranched or farmed during wet periods, only to be abandoned when there is a return to normal or to dry conditions. Narrowing profit margins and technology changes have also been driving forces behind the recent trend in farm consolidation in the Great Plains (Duncan et al. 1995). Because of the climate variability discussed above, and other factors which will be discussed subsequently, the socio-economic environment of the Great Plains today can be characterized by risk and marginality (Riebsame 1990).

The population that is left in the rural areas of the Great Plains is aging. The average age of the farm or ranch operator in the Great Plains is just under 55 years, and the percentage of residents over 65 is steadily increasing (University of Texas Population Research Center 1998) (Fig. 1-5, Table 1-1). Small size and remoteness of rural areas have proven to be liabilities and many rural economies are considered to be unsustainable (Drabenstott and Smith 1997, NRCS 1996).

Fig. 1-6: The services industry made up the largest piece of the Great Plains Gross Regional Product in 1996. Agriculture, forestry, and fisheries contribute the smallest piece, only about 2%. (Source: U.S. Bureau of Economic Analysis 1998)

Economy

The economy in the region is quite diverse and in both the central Great Plains and the entire Great Plains, the services sector contributes the most to the gross regional product, 19% and 18% respectively. Other sectors that contribute heavily to the gross regional product include manufacturing, government, finance, insurance, and real estate (Fig. 1-6). In both the central Great Plains and the larger region, construction, mining, agriculture, forestry, and fisheries make up the smallest parts of the gross regional product, although the contribution of these industries differ widely among states (US Department of Commerce 1998). The total market value of agricultural products sold in the region is over $24 billion. Thirty-five percent of this is from crops and 65% is from livestock (USDA Census of Agriculture 1997). Although the region is highly agricultural, with 90% of the land being used for agriculture, the contribution of agriculture to the gross regional product is very small, accounting for roughly two percent (Fig. 1-7). Although mining contributes little to the regional economy, it is extremely important on Native American reservations. In the West, 50% of the coal fields are on

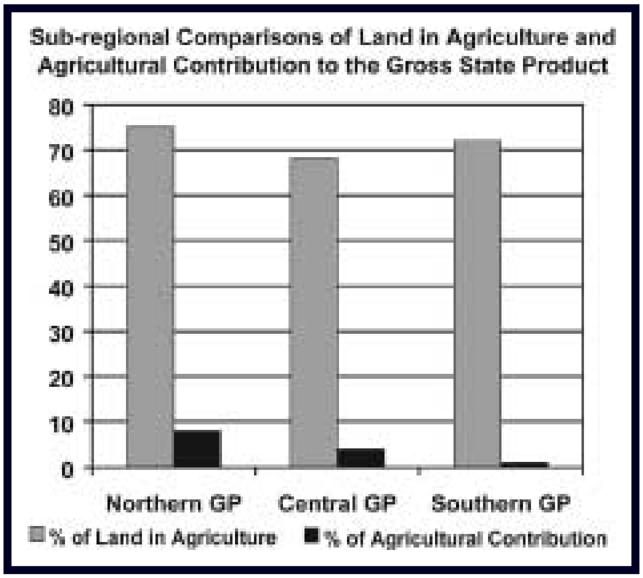


Fig. 1-7: Although agriculture controls about 70% of the land area in all three sub-regions of the Great Plains (Northern Great Plains = Montana, North Dakota, South Dakota; Central Great Plains = Wyoming, Nebraska, Colorado, Kansas; Southern Great Plains = Oklahoma, New Mexico, and Texas), the contribution of agriculture to the Gross Regional Product in very small. Agriculture is very important in the region for many reasons, but it is not a major player in the regional economy compared to other industries. (Source: U.S. Bureau of Economic Analysis 1998, USDA 1997 Census of Agriculture)

the lands of 22 tribes. Likewise, 25-40% of the nation's uranium, 33% of the coal, and 5% of the oil and gas are on reservations in the West (Fixico 1985). These minerals, and the rights to them, are often points of contention between Native Americans and others, and also among and within Native American tribes.

The market for products from the Great Plains is also highly variable and tied to the global market. In 1997, from four to 38% of the agricultural production from each state in the Great Plains was exported (USDA Census of Agriculture 1997). The variable market contributes to the agricultural economy's instability. Because the Great Plains has often times had marginal land and variable yields, the farmers are more vulnerable to market swings, with the international markets affecting the area even more than the national markets. The buffer in the past has been government subsidy programs, but these are being reduced. A positive sign for the farmers is a strong world food demand, and reduced world grain inventories, which is increasingly becoming a driver for land use decisions. Nevertheless, there is the threat of international competition as evidenced by a declining trend in real wheat prices since 1955.

The household economics of the residents of the Great Plains is often bleak. The average income is less than the national average, and the percentage of people below the poverty line is higher in the rural counties of the Great Plains than the national average (Licht 1997, University of Texas Population Research Center 1998) (see Table 1-1). In general, personal income per capita in 1998 was $21,100 in the rural counties of the Great Plains, and $26,800 in the urban counties of the Great Plains, compared to $27,200 for the entire US. Therefore, the region is lagging behind the average income for residents in other regions of the US.

Land Use

Agriculture is the primary land use transforming the Great Plains today, while urban and industrial uses are exerting increasing pressure on land availability and natural resource uses (Riebsame 1990, NRCS 1996). Agriculture, because of the extensive land resources occupied, is more important to the Great Plains region than to any other region in the country. Great Plains agriculture is land-extensive and uses relatively few chemical inputs and labor per unit of land. There are five major production systems in the Great Plains: range livestock, crop-fallow (a system where only half of an operator's land is planted in one year and the other half is left idle in order to restore productivity by accumulating water and nutrients), groundwater irrigation (aquifer-dependent), river valley irrigation (snowmelt-dependent), and intensive livestock feeding (Skold 1995).

The successes and failures of Plains agriculture are largely due to climatic constraints and market conditions for agricultural products. Conventional farming practices have resulted in severely reduced fertility and the loss of up to 50% of the soil organic matter by erosion and oxidation on many farm fields in the area since the beginning of this century (Parton et al. 1988). Conventional tillage practices are used on most cropland in the area but recent experiences with no- and minimum-till cropping show great promise. Despite the problems with agriculture in the Great Plains, the area is still a productive producer of agricultural products. Although the climate presents many difficulties to farmers and ranchers, the pattern of rainfall in the Plains also has some advantages. For example, limited rainfall reduces leaching of soil nutrients. Also, historically because the rain is concentrated in the growing season, crops receive water in the early stages of plant development when they need it the most. Likewise, because of the lack of rain during harvest time, plant diseases are not spread as easily. The topography of the Great Plains, much of it flat and virtually treeless, is also conducive to cultivation, especially where tractors or irrigation are needed (Hargreaves 1993).

About 80% of the land in the Great Plains is used for agriculture and ranching (Fig. 1-8). There are approximately 150,000 farms in the central Great Plains, covering over 158 million acres (USDA Census of Agriculture 1997). The average size of a farm in the region is about 1050 acres. Crops grown in the Great Plains vary according to the climatic gradients of rainfall and temperature. Plant growth is limited by precipitation and nutrient availability (Parton et al. 1994, Burke et al. 1994). The growing season in the Great Plains varies from 110 days in the Northern Great Plains to 300 days in the Southern Great Plains (NRCS 1996).

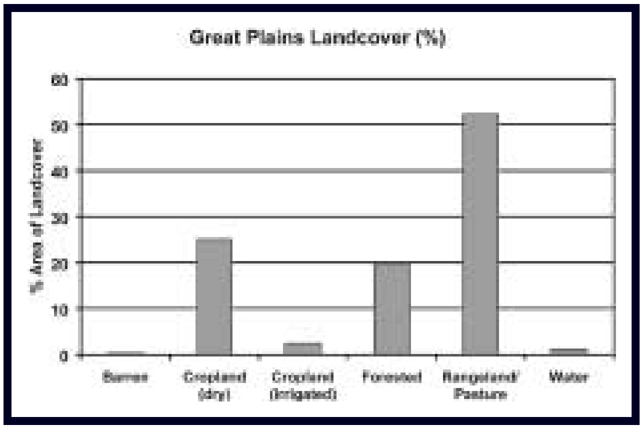


Fig. 1-8: Rangelands and pastures cover over 50% of the land area in the Great Plains, and croplands (both dryland and irrigated) cover another 25% of the land area. (Source: Loveland 1991)

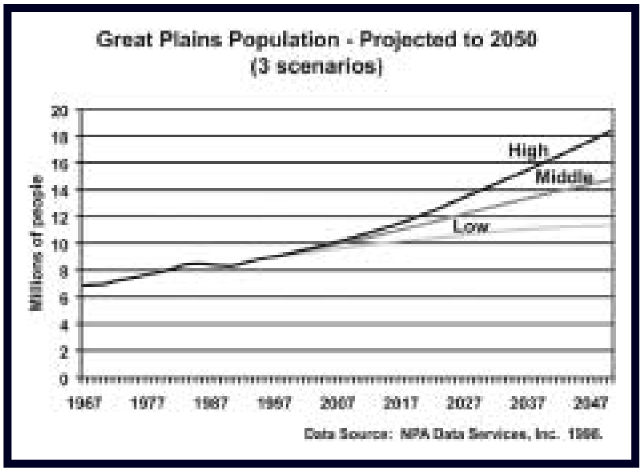


Fig. 1-9: Historical population trends and projections of population to 2050 in the Great Plains. All three scenarios project a population increase in the region in the future.

Wheat is the dominant cultivated crop on the agricultural land in the Great Plains. It is considered an 'indicator species,' meaning that changes in production area reflect various forces at play (i.e. economics and markets) during different periods. Rainfed corn and soybeans are produced in the east, dryland wheat and sorghum in the west. As productivity decreases along this east-west moisture gradient, risk of crop failure increases. Spring wheat is planted in the north and winter wheat in the south. Over 60% of the winter and spring wheat produced in the United States is produced in the Great Plains (USDA 1986). In irrigated areas there is more crop diversification, with onions, sugar beets, corn, and other crops being widely grown. Irrigated farms in the region number approximately 45,000 on over 14 million acres, which is 30% of the farms and 9% of the land area (USDA Census of Agriculture 1997). Also, other small grains, such as grain sorghum, hay, forage crops, and pastures, are grown to support the cattle industry (USDA 1986).

The remaining agricultural land in the Plains is grazing ground, mostly clustered in the dry western portion of the region (NRCS 1996). Land making up the non-agricultural portion of the Great Plains include urban areas, highways and railroads, and public preserves (Riebsame 1990). Many of these public preserves, or conservation or natural areas, are very important to the region and the country for wildlife habitat and maintaining biodiversity.

Agricultural operations are becoming larger, more corporate in structure, and more dependent on technological advances. Great Plains farms are on average three times larger than farms in other regions of the U.S. (Skold 1995). Although the region is highly diversified, undiversified agriculture at the farm level has often resulted from policy and market pressures, and from technological advances. This uniformity has contributed to an increase in weeds, pest problems, and loss of natural biodiversity on these farms. These changes in agricultural management have enabled the development of highly productive agricultural systems, but have also resulted in greater dependence on technological advances and greater vulnerability to environmental change.

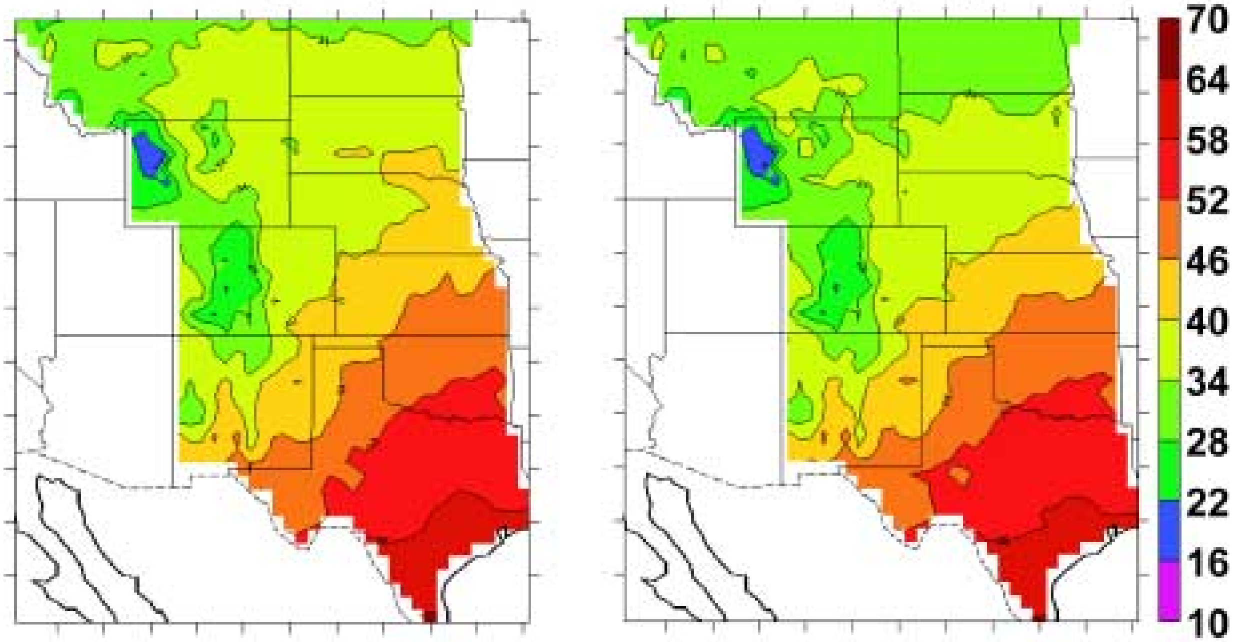
Potential Futures

The population of the Great Plains is expected to rise in the future; one projection shows an increase from about 9 million residents in the late 1990s to about 14 million in 2050 (NPA Data Services, Inc. 1998) (Fig. 1-9). Much of this increase will be seen in urban areas such as the Colorado Front Range. Figure 1.9 shows three projections (high, middle, and low) of the way the population may increase in the region. The number of jobs and incomes in the region were also projected to 2050 (NPA Data Services, Inc. 1998). The middle projection shows that the average income per household is projected to increase from $50,000 in 1997 to about $90,000 at 2050 (NPA Data Service, Inc. 1998). Likewise, the middle projection also shows that the number of jobs is projected to double during this period (NPA Data Services, Inc. 1998).

These possible changes in demographics and economics need to be kept in mind when thinking about potential climatic changes and their impacts. Climate change does not happen in a vacuum, and the social and economic situation of the region will have many implications for the way in which people cope or adapt, and with the speed at which they do so. Particularly important are the economics of coping. It should be emphasized here, however, that these are just possible projections to represent the range of what may happen to the population and the economy of the Great Plains in the future.

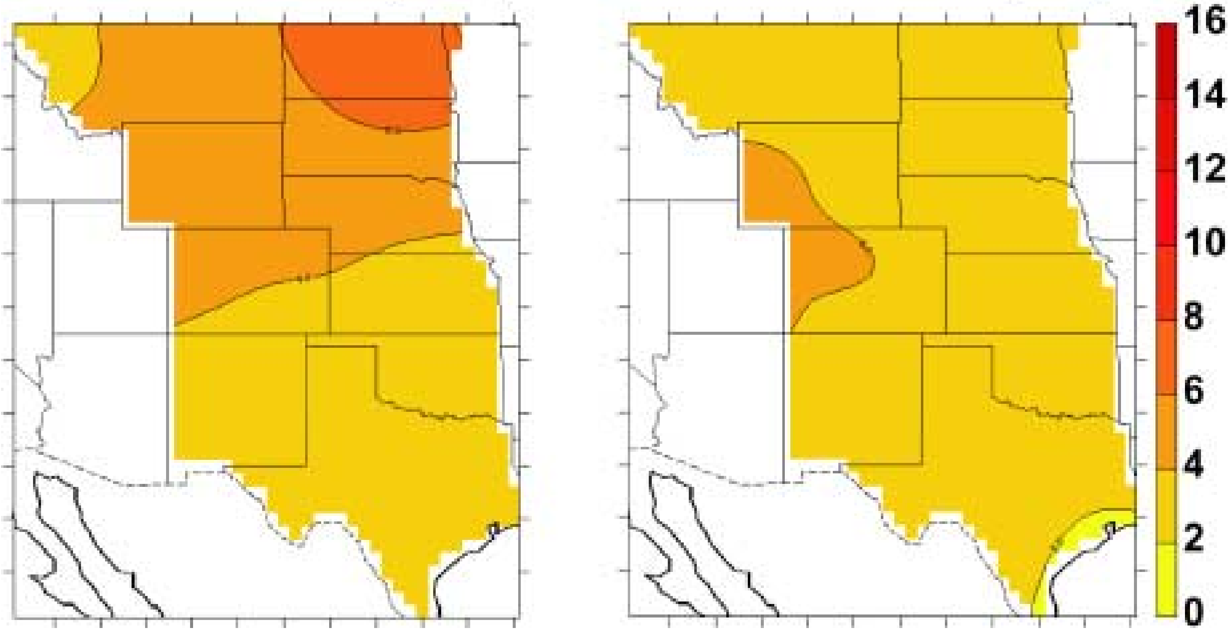
Both of the climate model scenario experiments used in this assessment project a possible future of the Great Plains as a warmer place in both 2030 and 2090 (Fig. 1-10a – p). The precipitation in the future is expected to both increase and decrease over different parts of the region during the 2030s and 2090s, with most increase seen at 2090 (Fig. 1-11a – h). These basic climatic changes, and possible ecosystem responses and impacts stemming from them, are what will be discussed in the remainder of this report.

Figure 1-10 (a-d): Minimum Temperature (°F) 2025-2034



a. 2025-2034 (CCC)

b. 2025-2034 (Had)

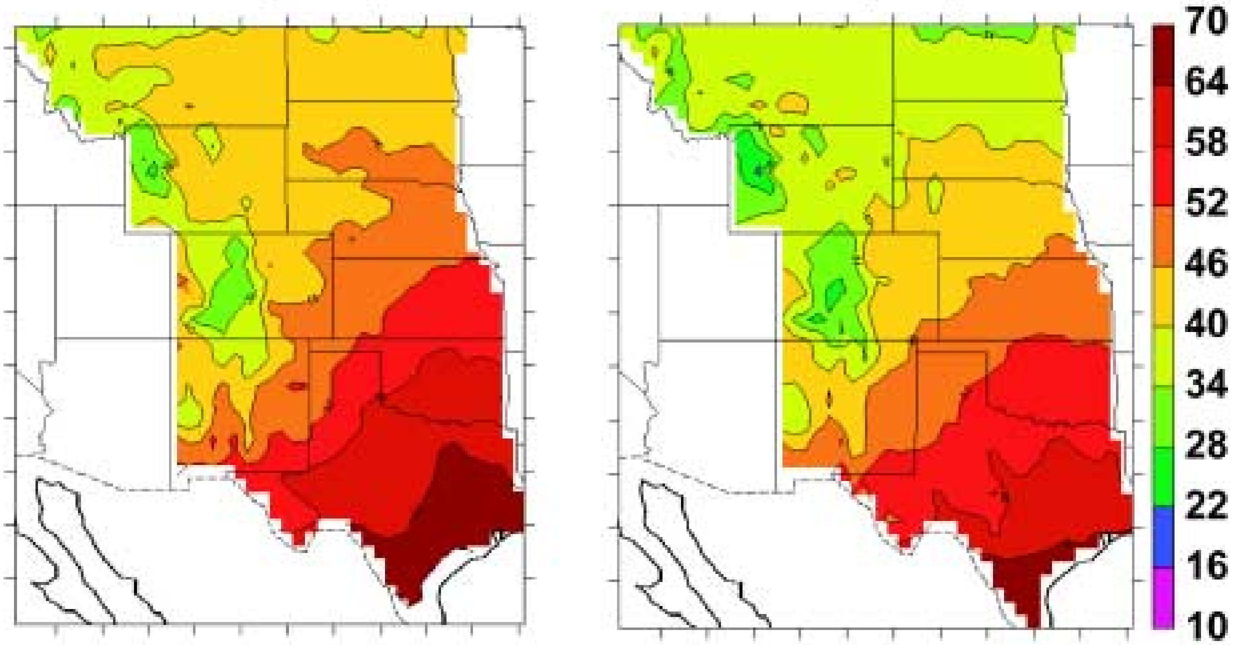


c. Difference between 2025-2034 and 1961-1990 (CCC)

d. Difference between 2025-2034 and 1961-1990 (Had)

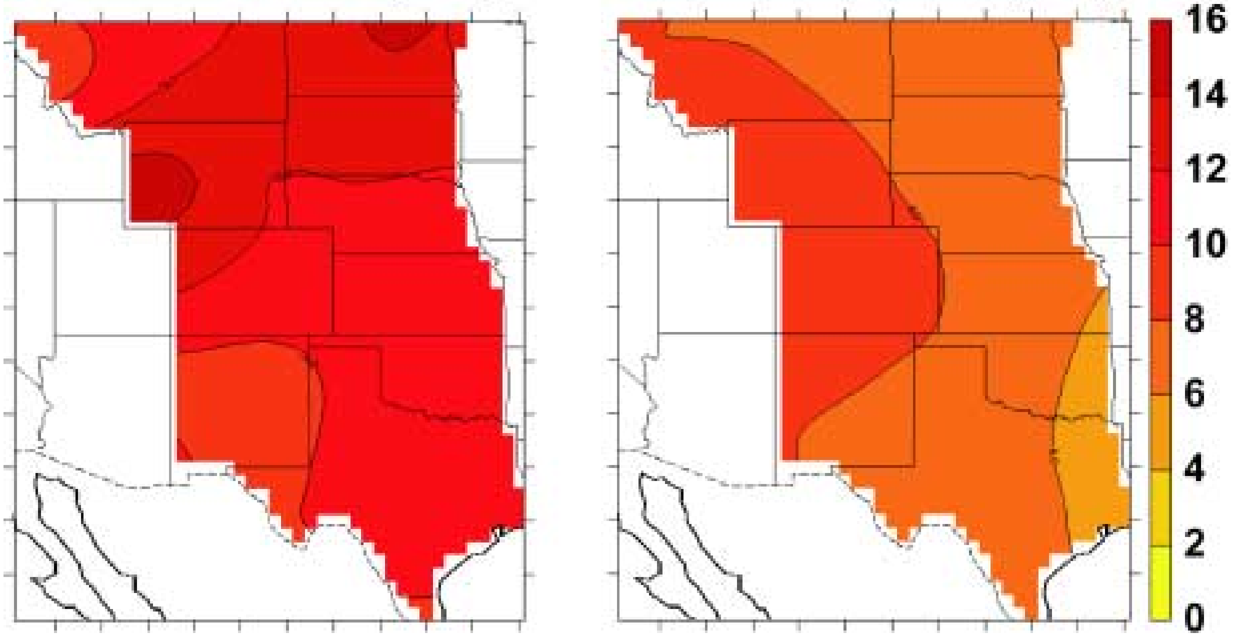
Fig. 1-10: Minimum (panels a-h) and maximum temperatures (panels i-p) over the Great Plains as projected by both model experiments at 2030 (average of 2025-2034) and 2090 (average of 2090-2099). Both the actual values (panels a-b, e-f, i-j, and m-n) and the deviations from the historical period (1961-1990) (panels c-d, g-h, k-l, and o-p) are shown. The projected increases in minimum temperatures are greater than the increases in maximum temperatures. The CCC model produces hotter results in both time periods.

Figure 1-10 (e-h): Minimum Temperature (°F) 2090-2099



e. 2090-2099 (CCC)

f. 2090-2099 (Had)



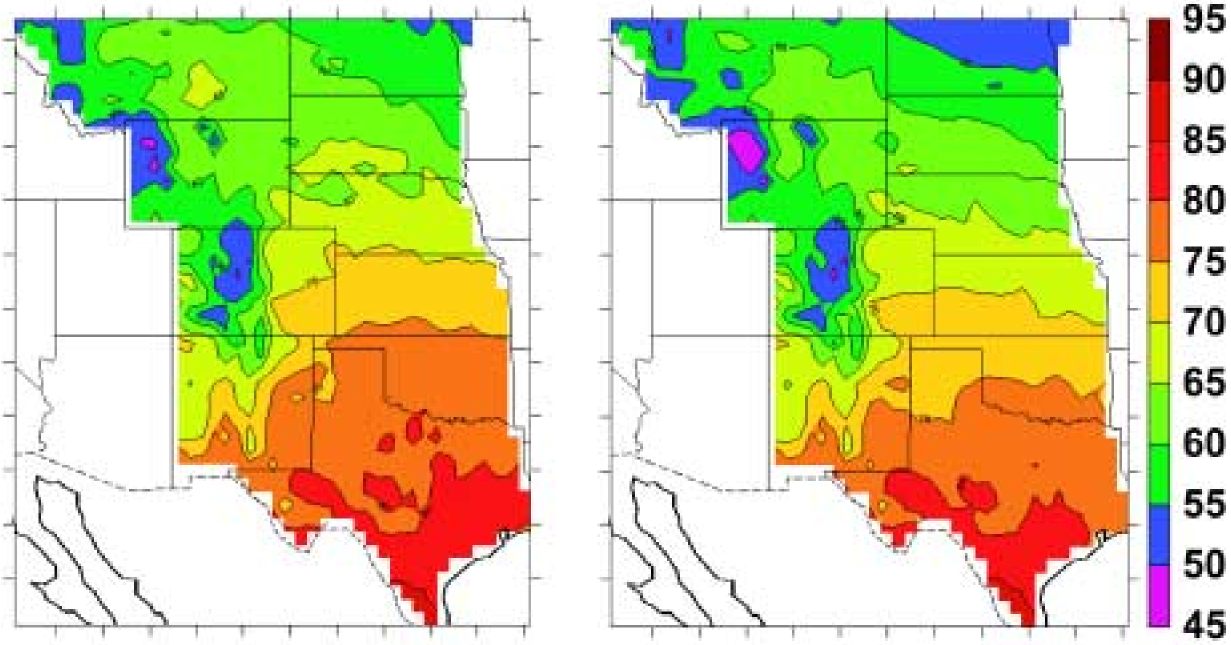
g. Difference between 2090-2099 and 1961-1990 (CCC)

h. Difference between 2090-2099 and 1961-1990 (Had)

Figure 1-10 (i-l): Maximum Temperature (°F) 2025-2034

i. 2025-2034 (CCC)

j. 2025-2034 (Had)



k. Difference between 2025-2034 and 1961-1990 (CCC)

l. Difference between 2025-2034 and 1961-1990 (Had)

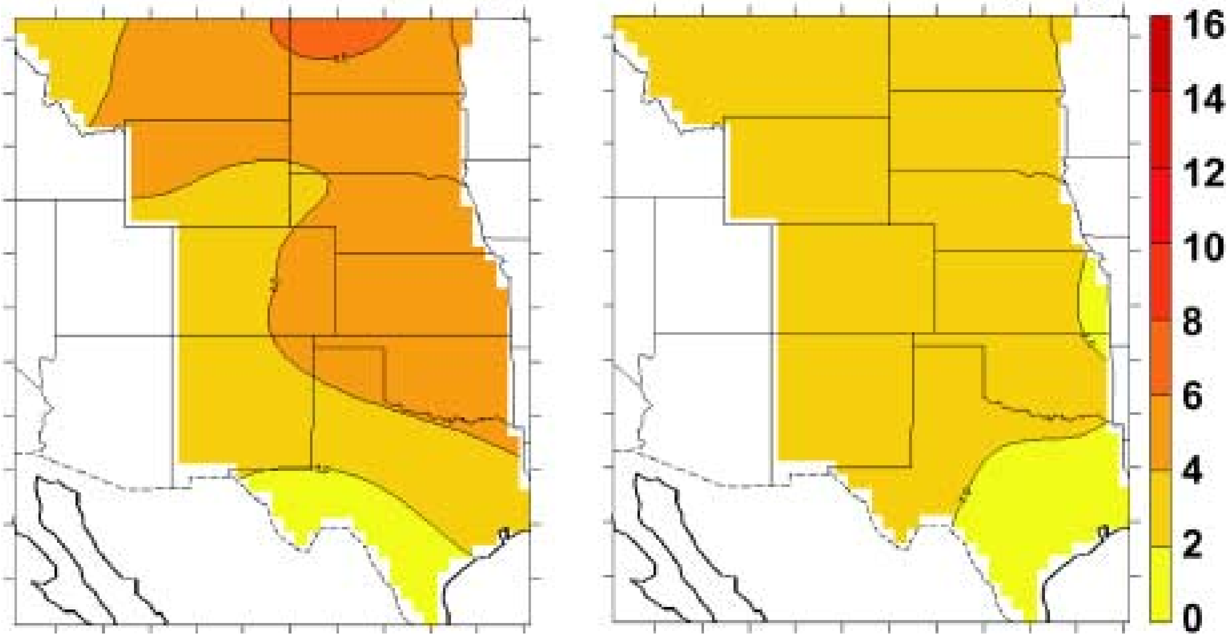
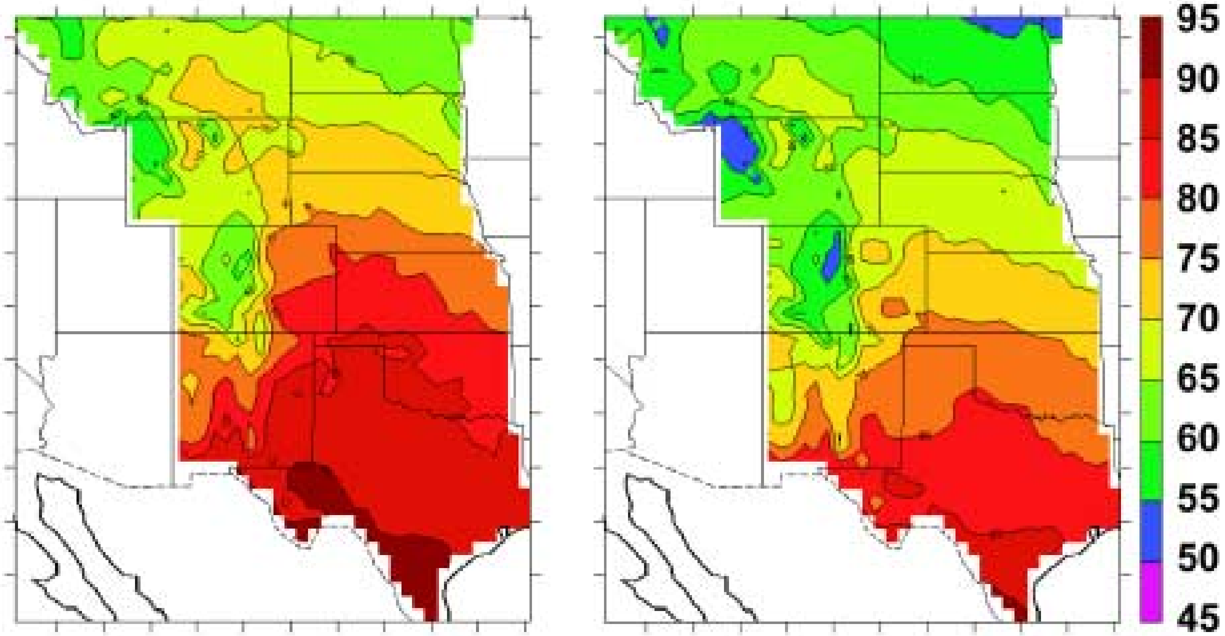


Figure 1-10 (m-p): Maximum Temperature (°F) 2090-2099

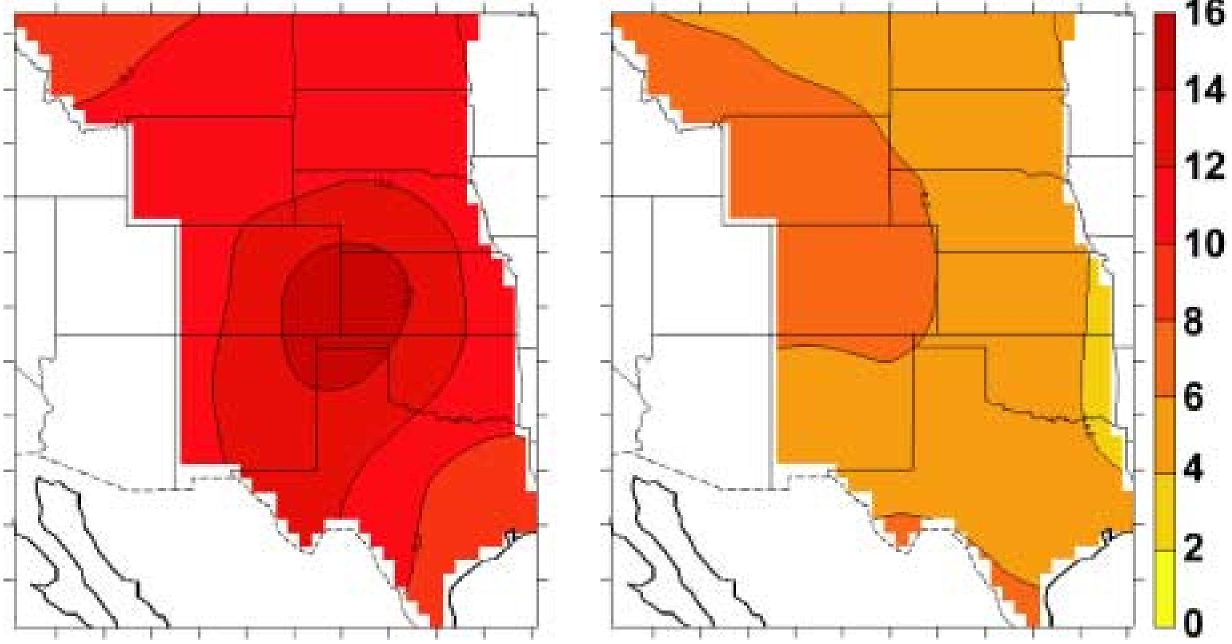


m. 2090-2099 (CCC)

n. 2090-2099 (Had)

o. Difference between 2090-2099 and 1961-1990 (CCC)

p. Difference between 2090-2099 and 1961-1990 (Had)



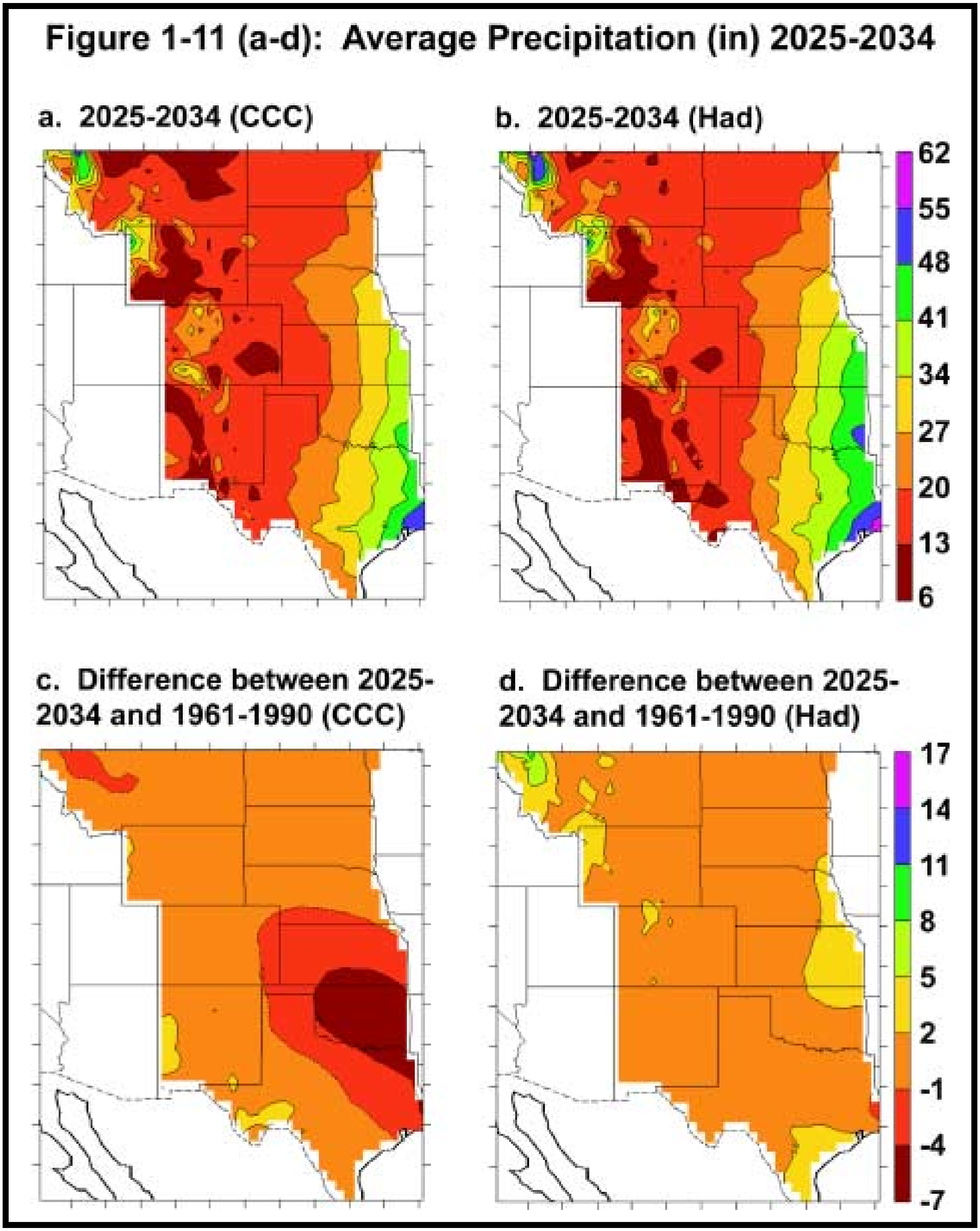
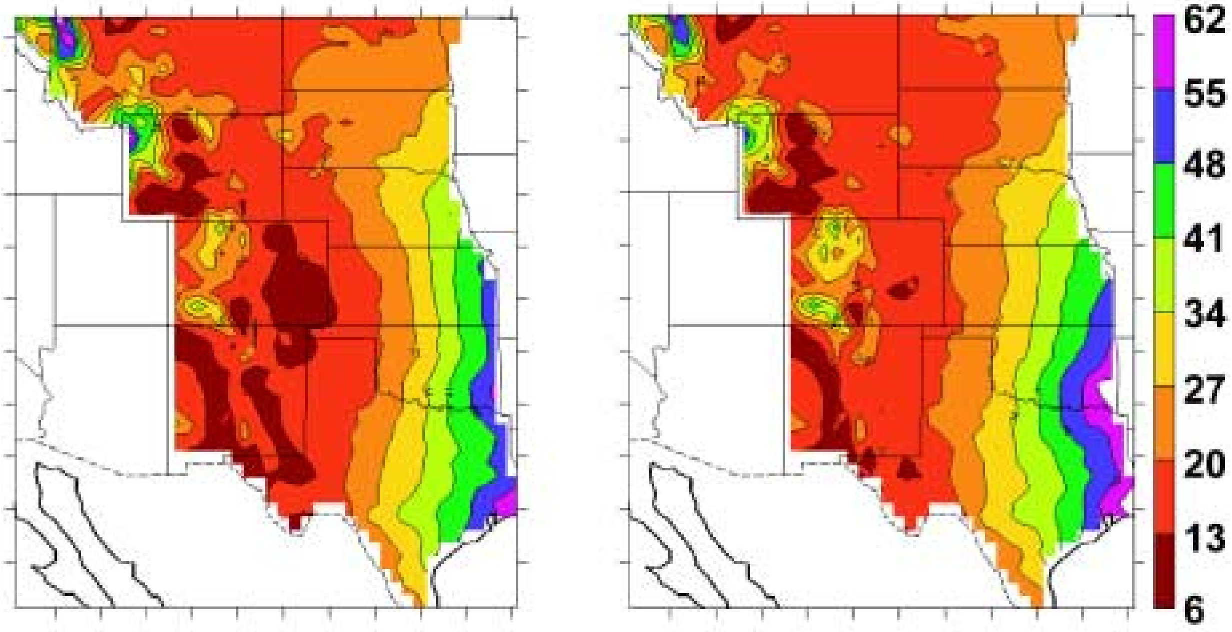


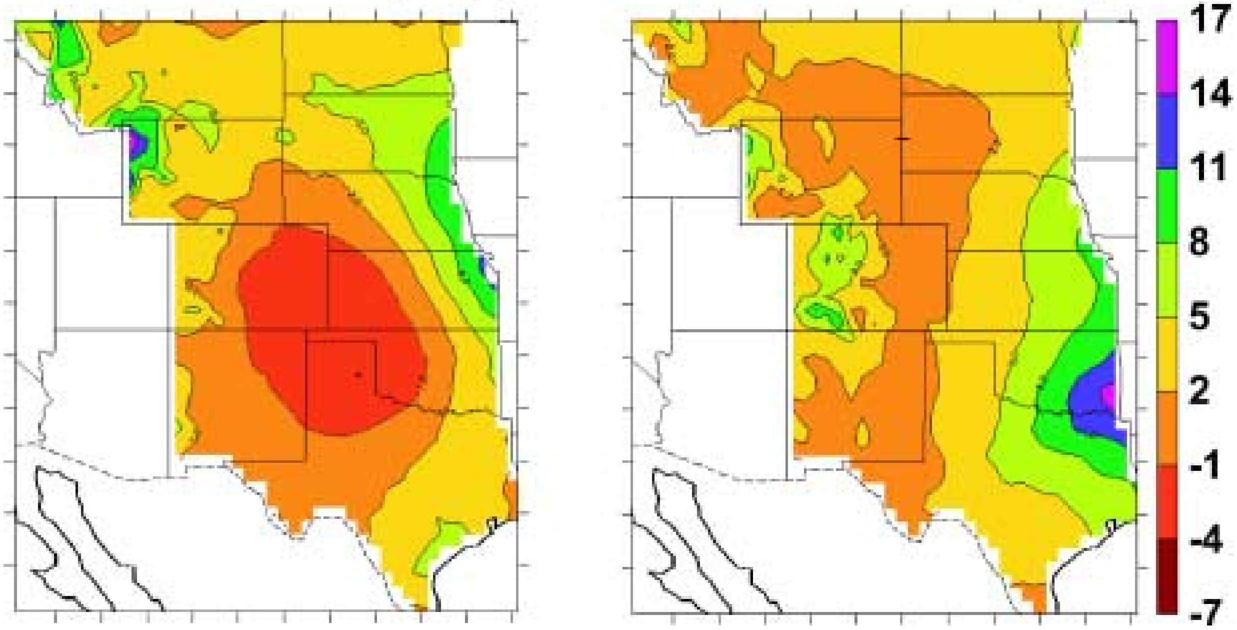
Fig. 1-11: Precipitation over the Great Plains as projected by both model experiments at 2030 (average of 2025-2034) and 2090 (average of 2090-2099). Both the actual values (panels a-b and e-f) and the deviations from the historical period (1961-1990) (panels c-d and g-h) are shown. The CCC model shows decreases in precipitation over parts of Oklahoma and Texas in both time periods, whereas, the Hadley model shows mainly slight to moderate increases in precipitation over the region.

Figure 1-11 (e-h): Average Precipitation (in) 2090-2099



e. 2090-2099 (CCC)

f. 2090-2099 (Had)



g. Difference between 2090-2099 and 1961-1990 (CCC)

h. Difference between 2090-2099 and 1961-1990 (Had)

Table 1-2: Characteristics of Great Plains land uses.

Parameter	Conservation Areas	Rangelands/Intensive Cattle Operations	Croplands
Vulnerability	High	High	Moderate
Land Cover	Wetlands Rangelands Forests Dunes	Rangelands Woodlands Savannas	Dryland crops Continuous corn Wheat-fallow Irrigated crops Hay
Land Use	Water conservation Soil conservation Grassland preserve National park Shelter belt	Grazing land Conservation Reserve Program (CRP) Feed lot	Cropland Fallow land Irrigated land
Land Management Agency	Dept. of Interior USDA non-governmental organizations (NGO)	Bureau of Land Management (BLM) USDA Bureau of Indian Affairs (BIA) Natural Resources Conservation Service (NRCS) Private	USDA State Private
Stakeholders	Conservationists Recreationists Hunters Fishermen	Ranchers Breeders Livestock sellers Feedlot owners	Farmers Seed sellers Crop insurers Grain buyers
Objectives	Broad	Intermediate	Specific
Management	Broad	Intermediate	Specific
Planning Horizons	Varied	Longer	Shorter

Sectoral Focus Groups

The four sectoral focus groups that are addressed in this assessment are: agricultural land use and adaptation (i.e. cropping systems); ranching, rangeland, and livestock; conservation and natural areas; and the cross-cutting sector, water. These sectors were picked because of their importance in the Great Plains (Table 1-2). The majority of the land in the Great Plains is used for agriculture, either crops or livestock. There are also many natural areas in the Great Plains that could be impacted by climate change. These systems are less managed than agricultural systems, and therefore impacts may be more pronounced if the systems are unable to adapt to changing conditions rapidly. Natural areas in the region include the prairie pothole areas in the Dakotas and the breeding ground for sandhill cranes and many other species of waterfowl in Nebraska. Likewise, one of the last remnants of the tall-grass prairie is in the Flint Hills which occurs in Kansas and Oklahoma. Water is important across all sectors in the Great Plains including its use in agriculture, and for urban and industrial uses, as well as in natural areas. Projections relating to the quantity and seasonality of precipitation are important for the whole of the Great Plains, as are scenarios relating to the competition for water among users.

Stakeholder Concerns

The stakeholders were invited to workshops convened to address potential changes in the region from projected climate changes with many questions and concerns about climate change and variability. Many of the stakeholders are farmers, ranchers, and land managers (Table 1-3) and because they are so intimately connected with the climate and the land, they were very interested in exploring possible future impacts. These impacts can include both opportunities and vulnerabilities, therefore, exploitation or coping strategies to deal with the possible changes were also discussed. The resiliency of communities and building sustainability were two important issues that were discussed. It was made clear though that production and conservation need to be equally important to achieve sustainability. Short-term goals, such as those often addressed by policy and economic considerations, need to advance long-term goals, such as sustainability.

The stakeholders asserted that climate change discussions that are linked with other issues vital to the survival of communities will produce the most benefit. They advocated a "least regrets" approach to the future. In this situation, vulnerabilities are evaluated so that even if the change does not happen, the coping strategies in place will still be beneficial. For example, increasing soil organic matter, which among other things increases soil water retention, will help farmers whether or not the growing season precipitation decreases due to climate change.

The impact of climate change on policies is a big concern to the stakeholders. They feel that keeping constituents involved in the policy discussions, so they can contribute to the development of policies, will lead to better, more-informed, beneficial policy responses. Avenues and mechanisms of information transfer need to be developed in the region. This role can be played by commodity groups, extension agents, consultants, or other groups. Additionally, the central Great Plains region, and the entire Great Plains region, has many tribal reservations included in it. These tribal lands were also considered in the impacts analysis as it is often harder for groups to adapt to climatic change where there are limited resources, such as on these tribal lands.

When considering the output from the scenarios, there needs to be consideration of the political and social structures, and how they will evolve, including the necessary infrastructures. When looking at opportunities or vulnerabilities caused by impacts, adaptation needs to be considered. Possible shifts in land use activity will need to be studied, as well as what the critical thresholds are that are keeping people from changing their land use.

To summarize the many conversations with stakeholders, four main points came out that are pursued further in this report. First, climate variability and extreme events are of much more concern to stakeholders than changes in average temperatures or precipitation amounts. It was stated frequently that it is much easier to adapt and cope with a steady change than with erratic conditions. Second, the adaptability of both human systems and ecosystems was discussed at length. Humans in the Great Plains have proved highly adaptive to perturbations over the years, but there is concern about the ability of natural or less-managed systems to adapt quickly to climatic changes under current and future socio-economic conditions. The rate of change, fast versus slow, will undoubtedly influence the rate of adaptation. Third, water was an important concern across the board with all stakeholder groups. Water concerns were expressed in terms of quantity, quality, timing, distribution, and form of precipitation. Finally, the conservation of soil organic matter, and the positive role this may play in buffering operators from climate change was discussed at length by many groups. From this also stems the possibility of developing a carbon strategy that will have broader conservation benefits.

Table 1-3: Stakeholder groups that attended assessment workshops.

Stakeholders
Farmers
Ranchers
Academics
Water Managers
Public Land Managers
Industry Representatives
Commodity Groups
Rural Organizations
State and Local Government
Conservation Groups
Scientists
Agricultural Extension Agents

These four issues will be discussed further in the report, following the chapters on climate scenario results and ecosystem responses.

EL NIÑO

(from the NOAA El Niño theme page – http://www.pmel.noaa.gov/tao/elNiño/el-Niño-story.html)

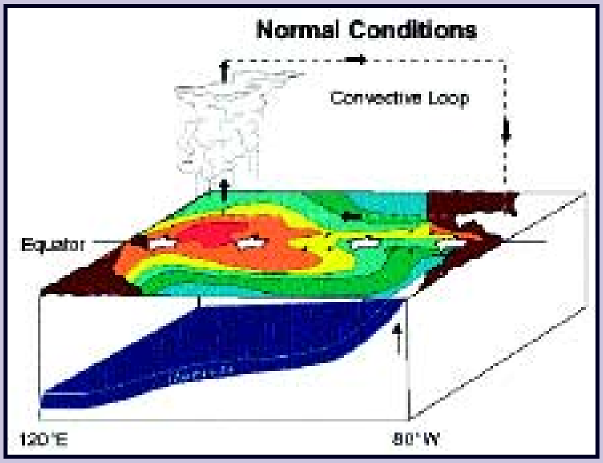
El Niño is a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe. Observations of conditions in the tropical Pacific are considered essential for the prediction of short term (a few months to 1 year) climate variations. To provide necessary data, NOAA operates a network of buoys which measure temperature, currents and winds in the equatorial band. These buoys daily transmit data which are available to researchers and forecasters around the world in real time.

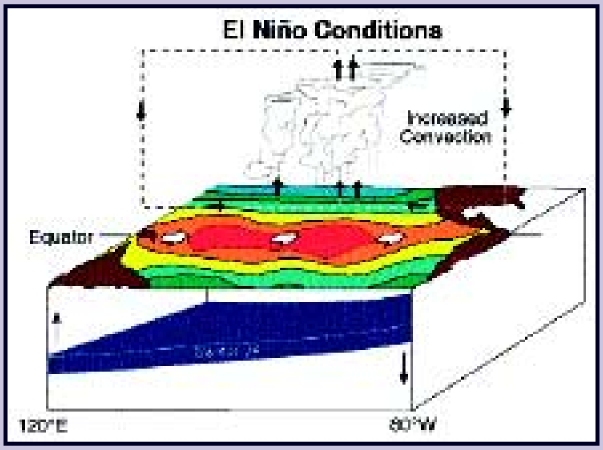
In normal, non-El Niño conditions (top panel of figure), the trade winds blow towards the west across the tropical Pacific. These winds pile up warm surface water in the west Pacific, so that the sea surface is about 1.6 ft (1/2 meter) higher at Indonesia than at Ecuador. The sea surface temperature is about 14.4° F (8° C) higher in the west, with cool temperatures off South America, due to an upwelling of cold water from deeper levels. This cold water is nutrient-rich, supporting high levels of primary productivity, diverse marine ecosystems, and major fisheries. Rainfall is found in rising air over the warmest water, and the east Pacific is relatively dry.

During El Niño (bottom panel of figure), the trade winds relax in the central and western Pacific leading to a depression of the thermocline in the eastern Pacific, and an elevation of the thermocline in the west. This reduces the efficiency of upwelling to cool the surface and cuts off the supply of nutrient rich thermocline water to the euphotic zone. The result is a rise in sea surface temperature and a drastic decline in primary productivity, the latter of which adversely affects higher trophic levels of the food chain, including commercial fisheries in this region. The weakening of easterly tradewinds during El Niño is also evident. Rainfall follows the warm water eastward, with associated flooding in Peru and drought in Indonesia and Australia. The eastward displacement of the atmospheric heat source overlaying the warmest water results in large changes in the global atmospheric circulation, which in turn force changes in weather in regions far removed from the tropical Pacific.

La Niña is characterized by unusually cold ocean temperatures in the Equatorial Pacific, compared to El Niño, which is characterized by unusually warm ocean temperatures in the Equatorial Pacific.

The impacts of the El Niño and La Niña cycles can also be discerned in the Great Plains. Regional aridity in the High Plains is controlled by variation in precipitation during the growing season (spring and summer). Most localized thunderstorms in the region originate as small storms over the Front Range of the Rocky Mountains, a result of differential heating of the mountain slopes. Generally, dry conditions prevail across central North America during the La Niña phase. Relatively small changes in atmospheric circulation in the Northern Hemisphere can lead to widespread drought in the Great Plains (Forman et al. 2001).





CHAPTER 2:

CLIMATE CHANGE SCIENCE AND SCENARIO RESULTS

Climate Change Science and Scenario Results

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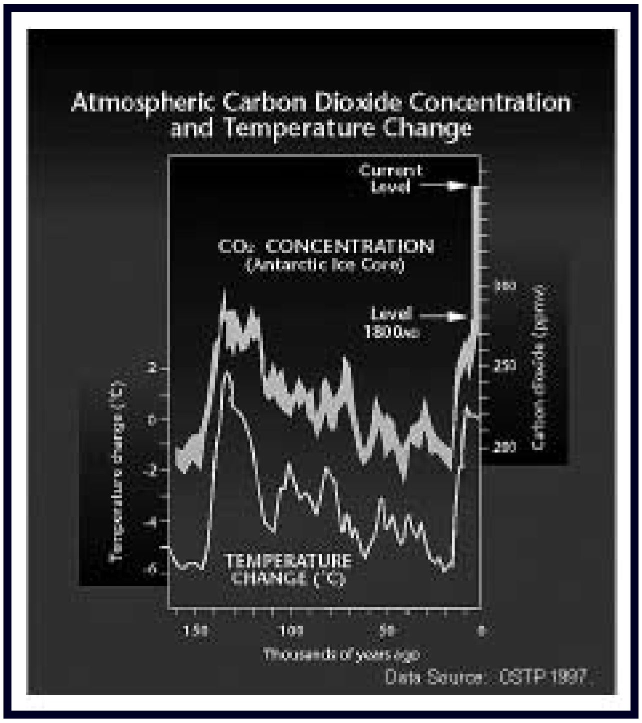
Climate Change Science

Climate change science has been a hotly debated topic over the past several years. There is no debate regarding the rapid build-up of carbon dioxide (CO_2) and other so called “greenhouse gases” in the atmosphere during the past 200 years, nor that the increase is due to human industry and other activities, such as deforestation and land use changes. This rapid increase in atmospheric CO_2 concentrations is of great concern because of the role it can play in warming the earth and the subsequent effects on ecosystems and humans. The rate of increase, 30% since the Industrial Revolution, is unparalleled in the history of the world’s climate recorded in the layers of sediment that accumulated over thousands of years in ice and rock, called the “paleorecord” (Houghton 1997).

The reason that increasing CO_2, and other “greenhouse gases,” can cause climate change has to do with the properties of the gases. CO_2 is a good absorber of heat radiation from the Earth’s surface. It acts as a blanket which traps heat trying to radiate from the surface of the Earth. This process is termed the “greenhouse effect.” With the increased temperatures caused by the heat that is trapped, the amount of water vapor in the atmosphere increases, also contributing to the greenhouse effect, and in turn causing more warming. However, clouds have the opposite effect; they are net coolers of the Earth’s surface because they reflect some of the incoming solar radiation back into space. Particles in the atmosphere, such as aerosols (tiny particles in the air from pollution), also absorb radiation from the sun and scatter it back into space. Therefore, they, along with clouds are net coolers because less solar radiation is reaching the surface of the earth. Particulates, including aerosols, can dissipate in several days or weeks, whereas greenhouse gases have a much longer life in the atmosphere, decades to centuries. Natural causes of particulates are dust, forest fires, sea spray, and volcanoes. Human activities that release sulfates and particulates include the burning of biomass and fossil fuels.

The “enhanced greenhouse effect” is the added effect caused by increases in greenhouse gases present in the atmosphere due to human activities, such as the burning of fossil fuels and deforestation (Houghton 1997). Methane, which is also a greenhouse gas that has been increasing since the Industrial Revolution, is released through the leakage of natural gas pipelines and oil wells, rice cultivation, cattle, decay of trash in landfills, and wood and peat burning. Carbon dioxide (CO_2) contributes 70% of the enhanced greenhouse effect, methane (CH_4) contributes 24%, and nitrous oxide (N_2O) contributes 6% (Houghton 1997).

The rate of warming in the last 150 years is also a concern. In the last century the average global temperature has increased by 4.5° F (2.5 °C) (Houghton 1997). This is faster than the global average temperature has changed at any time over the past 10,000 years (Fig. 2-1). An increase of 4.5° F (2.5 °C) may not sound like a large increase, but the difference in average global temperature between the coldest part of the last ice age and the warm period between the ice ages is 9-10.8 °F (5-6 °C) (Houghton 1997).



Data Source: OSTP 1997.

Fig. 2-1: Atmospheric CO_2 levels have varied with the temperature over the last 150 thousand years. The rate of CO_2 increase in the last 200 years is unprecedented in the paleo-record.

We do not mean to imply that there is no uncertainty about the rate of change or the impacts of these climatic changes. Much to the contrary, there are numerous sources of uncertainty including: future emissions of greenhouse gases and sulfate aerosols (and their resulting levels in response to changing economies and policies), global and regional climate responses to these emissions and other altered forcings (e.g., land cover and land use change), and surface hydrological and ecological responses to climate change. Although there are uncertainties, climate and ecological models, while not perfect, can give us a state-of-the-science assessment of the sensitivity of climate and ecosystems to altered forcings. Some of the uncertainties already uncovered in this assessment include, the lack of understanding of the regional patterns of the potential warming and changes in precipitation, and the temporal variability in the projections, dealing with the potential rates of change. Also, the possible effects of this increase in temperature, are not well understood in most areas. Some of the uncertainties will be worked through, and others will undoubtedly be exposed. Nevertheless, the assessments of climate change impacts under given climate scenarios provide important information about the sensitivity of the Great Plains to a set of possible future climate conditions.

Scenario Results

The results presented in this section for the decades of 2030 and 2090 were generated by experiments using the Canadian Climate Centre (CGCMI) model (hereafter referred to as CCC) (Boer et al. 2000) and the UKMO-Hadley Center (HADCM2) model (hereafter referred to as Hadley) (Mitchell et al. 1995). These experiments are driven by the historical concentration of greenhouse gases from the beginning of the runs to the present, with concentrations increasing by 1 %/year after 1989. The effects of sulfate aerosols are also included in both models. See Appendix C or the National Assessment website <http://www.nacc.usgcrp.gov> for a more in-depth description of these two climate sensitivity experiments and corresponding models. Future climate scenarios based on the CCC and Hadley general circulation model (GCM) experiments are included in the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) climate dataset (Kittel et al. 1997, Kittel et al. 2000) and are used extensively in this assessment. Many of the analyses presented in this report, such as the tables in this chapter and the next, are derived from this VEMAP historical and scenario climate dataset. These two scenarios are not predictions of future climate, and do not account for many uncertainties mentioned above that may influence future climates. However, the two scenarios show a plausible range of what conditions might be like in the Great Plains in the future.

These results are averaged over all ten of the Great Plains states, not for only the four Central Great Plains states. Because seasonality is very important to our stakeholders, annual averages are supplemented with seasonal averages for some variables. The model experiments both project a continuation of the historical trends seen in Great Plains climate: increased warming, and for some areas, greater precipitation. In general, the Canadian model experiment produced a greater increase in temperature, especially in the winter, than did the Hadley model experiment. Both model experiments showed both increases and decreases in precipitation over the region and the seasons, although there seems to be a slightly wetter trend in the region, especially at 2090.

Maximum and minimum temperatures rise in both scenarios (Fig. 2-2, 2-3). Minimum temperature increases are greatest, indicating increased nighttime and winter warming; by the 2090s, the increase is over 7° F (3.9° C). In the CCC scenario, minimum temperature increases are greatest in the eastern parts of the Great Plains, particularly in North and South Dakota and Nebraska, whereas in the Hadley scenario the increase in temperature is more uniform over the region (see Fig. 1-10g-h). The increase in maximum temperatures is most pronounced over a multi-state area centered on the Oklahoma and Texas panhandles in the CCC scenario, whereas the results from the Hadley scenario portray a more even heating over the region (see Fig. 1-10k-l). Projections of precipitation are highly variable over the region, but for the CCC scenario the general pattern is related to the temperatures, with an area of slight to moderate drying appearing over a multi-state area centered over the panhandles of Oklahoma and Texas by 2090. The Hadley scenario portrays moderate increased precipitation over the eastern Great Plains, and steady to slight decreases over the western Great Plains (see Fig. 1-11g-h). In both of the scenarios, the snow season in the Great Plains ends earlier in the spring, reflecting greater warming in winter and spring.

As a consequence of these general results related to temperature and precipitation, there are other probable impacts that may follow. These include the possibility of an intensified hydrological cycle and increased evapotranspiration, chance of droughts, snowmelt runoff, heavy rains, and early fall and late spring snows. Many of these impacts result from an intensified hydrological cycle, and they may seem contradictory at first, but both droughts and heavy rains may occur more frequently in the future due to the change in the temperature and precipitation regimes. These impacts are of great concern to the stakeholders in the region, and they are discussed further in the remainder of the report.

The following tables (Table 2-1, Table 2-2) show the range of deviations in 2030 and 2090 from the conditions over the period of 1961-1990 (the "baseline" period) as projected by the two models. Both annual averages and seasonal averages are included for selected variables relevant to productivity and livelihoods on the Great Plains. (See Appendix F for metric unit tables.)

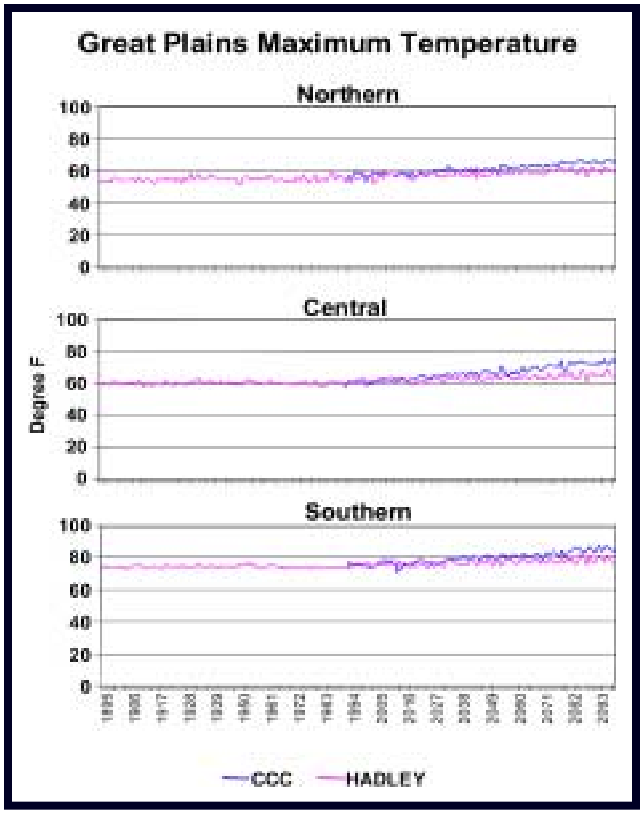


Fig. 2-2: Two hundred years of Great Plains maximum temperatures are shown here. The first 100 years represent historical data, and the last 100 years shows results from the two climate model experiments. There is a trend towards increasing maximum temperatures into the future. (Source: Kittel et al. 1997, Kittel et al. 2000)

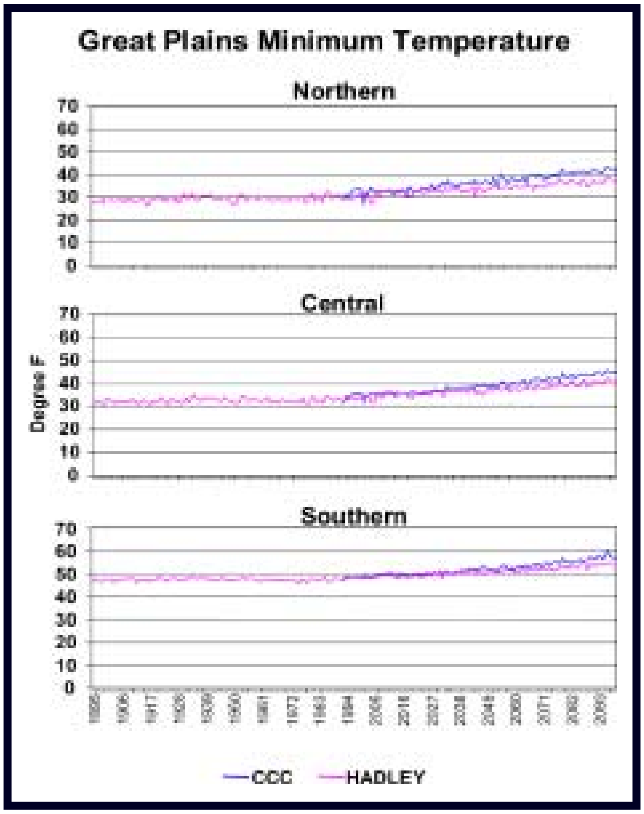


Fig. 2-3: Two hundred years of Great Plains minimum temperatures are shown here. The first 100 years represent historical data, and the last 100 years shows results from the two climate model experiments. There is a trend towards increasing minimum temperatures into the future. (Source: Kittel et al. 1997, Kittel et al. 2000)

Table 2-1: Annual Results: The range shows the deviations of the parameters from the baseline period (1961-1990) in the CCC and Hadley model scenario experiments.

Parameter	2030☆	2090
a. Average temperature (°F)	+3 to +3.9	+6.6 to +10.9
b. Average precipitation (in)	-1.22 to +0.9	+3.2 to +4.7
c. Runoff (in/yr)	-0.5 to +0.2	+0.5 to +1.3
d. Snowpack (in)	-0.09 to -0.04	-0.14 to -0.09
e. Heat Events (3 or more days ≥100°F)	+1.2 to +1.4	+2.7 to +4.1
f. Hot Days (# of days ≥100°F)	+7.9 to +8.1	+20.8 to +34.0
g. Cold Days (# of days ≤ 32°F)	-36.5 to -26.7	-72.7 to -62.9
h. Growing Degree Days (45°F)	+354.1 to +414.1	+824.3 to +1323.3
i. Soil Carbon (tons/acre)*	-0.06 to -0.05	-0.01 to 0
j. Net Primary Productivity (tons/acre/yr)*	+0.01 to +0.07	+0.12 to +0.17

a. absolute change in degrees Fahrenheit
b. absolute change in inches of precipitation
c. absolute change in inches of runoff per year
d. absolute change in inches of snowpack
e. change in the number of heat events (3 or more days that exceed or equal 100°F)
f. change in the absolute number of hot days at or over 100°F
g. change in the absolute number of cold days at or below 32°C
h. absolute change of growing degree days at the 45°F threshold
i. absolute change in tons/acre of soil carbon
j. absolute change in tons/acre/yr of NPP

* 1 ton = 2000 lbs.

☆ The values in the 2030 column are the differences in the annual average of the parameter over the time period between the decade of 2025-2034 and the baseline period (1961-1990). The values in the 2090 column are the differences in the annual average of the parameter over the time period between the decade of 2090-2099 and the baseline period (1961-1990).

Table 2-2: Seasonal Results: The range shows the deviations of the parameters from the seasonal averages of the baseline period (1961-1990) in the CCC and Hadley model scenario experiments.*

	2030☆				2090			
Parameter	**winter**	**spring**	**summer**	**fall**	**winter**	**spring**	**summer**	**fall**
a. Average temperature (°F)	+3.5 to +4.8	+2.6 to +4.6	+2.6 to +2.9	+2.9 to +3.5	+7.8 to +13.6	+5.2 to +11.4	+7 to +8.7	+6.3 to +9.8
b. Average precipitation (in/season)	-0.5 to +0.5	+0.2	-0.6 to -0.3	-0.4 to +0.3	+1.2 to +1.6	+1.3 to +1.9	-1.2 to +0.6	+1 to +1.6
c. Runoff (in/season)	-0.1 to +0.1	-0.2 to +0.1	-0.2 to 0	0 to +0.1	+0.1 to +0.3	+0.1 to 4 +0.4	-0.1 to +0.3	+0.4
d. Extreme rainfall events (> 2 in/24 hrs)	-0.9 to -0.1	0 to +0.1	-0.1 to +0.2	-0.1 to +0.2	-0.5 to -0.1	+0.2	0 to +0.1	+0.3 to +0.4

☆ The results presented here are the differences between the seasonal average of the parameter over the time period between the decade of 2025-2034 and 2090-2099, and the baseline period (1961-1990).

* winter = December, January, February
spring = March, April, May
summer = June, July, August
fall = September, October, November

a. absolute change in degrees Fahrenheit
b. absolute change in inches of precipitation
c. absolute change in inches of runoff over the season
d. change in the number of extreme rainfall events (exceeding 2 inches of precipitation in 24 hours)

These general results will be used in the next section, ecosystem responses, in order to evaluate some of the possible impacts to crops, rangelands and livestock, natural systems, and water.

CHAPTER 3:

ECOSYSTEM RESPONSES

Ecosystem Responses

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Climate Change Impacts in the Great Plains

The evidence for climate change is becoming more compelling, yet most regions of the United States do not have a strategy to deal with the potential impacts of climate change. In the Central Great Plains region (i.e., the Colorado, Kansas, Nebraska and Wyoming area), the potential impact of climate changes may affect winter snowfall, growing season rainfall amounts and intensities, minimum winter temperatures, and summer-time average temperatures. The combined effect of these potential changes in weather patterns and average seasonal climate can affect numerous sectors critical to the economic, social, and ecological welfare of this region.

In the Great Plains, three sets of natural resources are closely linked to climate and are key factors in the sustainability of ecological and social systems in the region. These resources are water, plants, and soil.

Water is critical due to the semiarid nature of the region and the interdependence across sectors sharing the use of water. The difficulty of managing water use among the various sectors is exacerbated by the uncertainty related to climate change projections. This assessment considers the possible changes in precipitation that will impact water use and supply to various agricultural sectors, urban and industrial uses, and natural ecosystems.

The diverse plant communities and ecosystems that populate the Great Plains are sensitive to changes in habitat and climate patterns. Many of the species that thrive in the Great Plains have adapted to the variable rainfall patterns and the warm moist summers. Agricultural and livestock industries have also adjusted to the weather patterns of the past three decades. The effect of climate change on the amount and timing of rainfall and the effect on growing season length of plant production are critical factors that can be evaluated with current analyses.

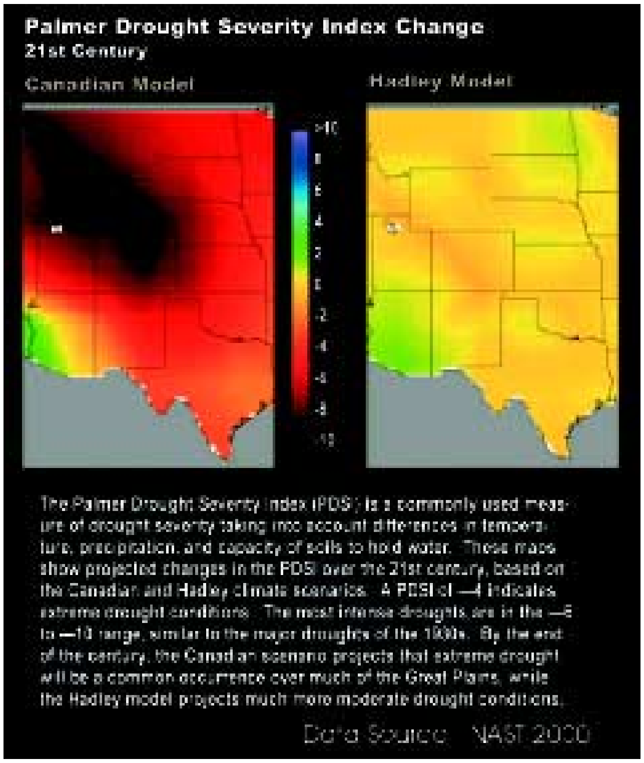
This chapter will focus on the impacts of climate change on water resources, including water supply, wetlands and agricultural water management, and agricultural and biological resources, including plant productivity and soil resources. The quantified analyses presented in this chapter include the evaluation of changes in water available for plant growth (AET), plant productivity (NPP), and soil fertility (SOM). There are many other important analyses that were not performed for this study. A brief discussion of these issues is included at the end of the chapter in the 'Research Needs' section.

Climatic Impacts on Water Resources

Changes in land use and climate will affect water quantity and quality. Projections of the two general circulation model scenarios indicate that both annual average temperatures and total annual precipitation will increase over the region during the coming century. Analysis of these projections indicate that water resources may be more severely impacted if the conditions prevail as suggested by the GCM scenarios, because the fairly large increase in temperature will offset the more moderate projected increases in precipitation. A 7.2° F (4° C) temperature increase is projected for the winter period at the end of this century for the Colorado-Wyoming area. This, coupled with about a 50% increase in winter-time precipitation, will greatly modify the amount and timing of snow-melt from the Rocky Mountains, with a possible earlier snowmelt (Miller 1997). During the summer months, minimum temperatures (nighttime) are projected to increase more than the maximum temperatures (daytime). The change in minimum temperatures may affect plant communities by increasing the amount of cool-season plant species (Alward et al. 1999). Likewise, this temperature pattern reduces the recovery opportunities from heat stress for livestock. These changes in temperatures may increase evaporation, and in turn precipitation, so the hydrological cycle may also be affected, resulting in more intensive convective storm activity.

Water is a critical component of the socio-economic activities contributing to the land transformations taking place in the Great Plains. Thus, the issue of water quality and supply is of particular importance to the inhabitants of this region. About 10% of the Great Plains cropland area, or 20 million acres, is irrigated cropland. The potential lack of water availability, due to increased temperatures and evaporation, could exacerbate the soil moisture stress of irrigated and non-irrigated regions of the Great Plains. Soil moisture depletion can greatly reduce yield of range forage and of crops. In addition, many parts of the Great Plains are showing decreasing water supplies for agriculture, partly due to higher value uses in urban areas.

The effect of the climate scenarios on drought stress was simulated using the Palmer Drought Severity Index (PDSI). The geographical pattern of the projected increased moisture stress at the end of 2100 indicates a drying out of much of the Great Plains by the CCC scenario, because the increased precipitation is offset by the higher temperatures (Fig. 3-1). The Hadley sce-



The Palmer Drought Severity Index (PDSI) is a commonly used measure of drought severity taking into account differences in temperature, precipitation, and capacity of soils to hold water. These maps show projected changes in the PDSI over the 21st century, based on the Canadian and Hadley climate scenarios. A PDSI of —4 indicates extreme drought conditions. The most intense droughts are in the —6 to —10 range, similar to the major droughts of the 1930s. By the end of the century, the Canadian scenario projects that extreme drought will be a common occurrence over much of the Great Plains, while the Hadley model projects much more moderate drought conditions.

Data Source: NAST 2000

Fig. 3-1: The CCC model experiment projects the possibility of severe droughts in the Great Plains at the end of this century. The Hadley model projects much less severe drought potentials.

nario portrays the region with much more moderate drought conditions. These projected trends in future drought occurrences are consistent with the changes in precipitation and temperature in the region generated from the two GCM scenarios.

The historical climate and projected climate change scenarios were used to simulate changes in evapotranspiration (ET) for different land cover and uses in the region. Estimates of ET rates are derived from the Century model simulations (Parton et al. 1994, Ojima et al. 1993, VEMAP 1998) as part of the VEMAP contribution (Schimel et al. 2000) to the National Assessment of Climate Change Impacts. Over the central portion of the region, the annual actual evapotranspiration (AET) was approximately 20 in/yr (500 mm/yr) during the 1961 to 1990 period. Croplands tended to have the greatest AET rates due to increased irrigation rates over the past 50 years, a result of the increased water available for evapotranspiration (Table 3-1). The values are similar to the rest of the Great Plains, except for the wetter, eastern portion of the Great Plains. The trends in AET from the grassland and the winter wheat ecosystems follow the trends in precipitation associated with the two climate change scenarios (Fig. 3-2a, 3-3a, 3-4a). Grasslands and croplands, occupying the more semi-arid areas of the region, tend to consume a greater proportion of the incoming precipitation, tending to release about 85 to 90% of the precipitation back to the atmosphere through evapotranspiration. The forested areas expend less of their AET to the atmosphere, with AET accounting for less than 80% of the incoming precipitation during the historical period, 1961 to 1990.

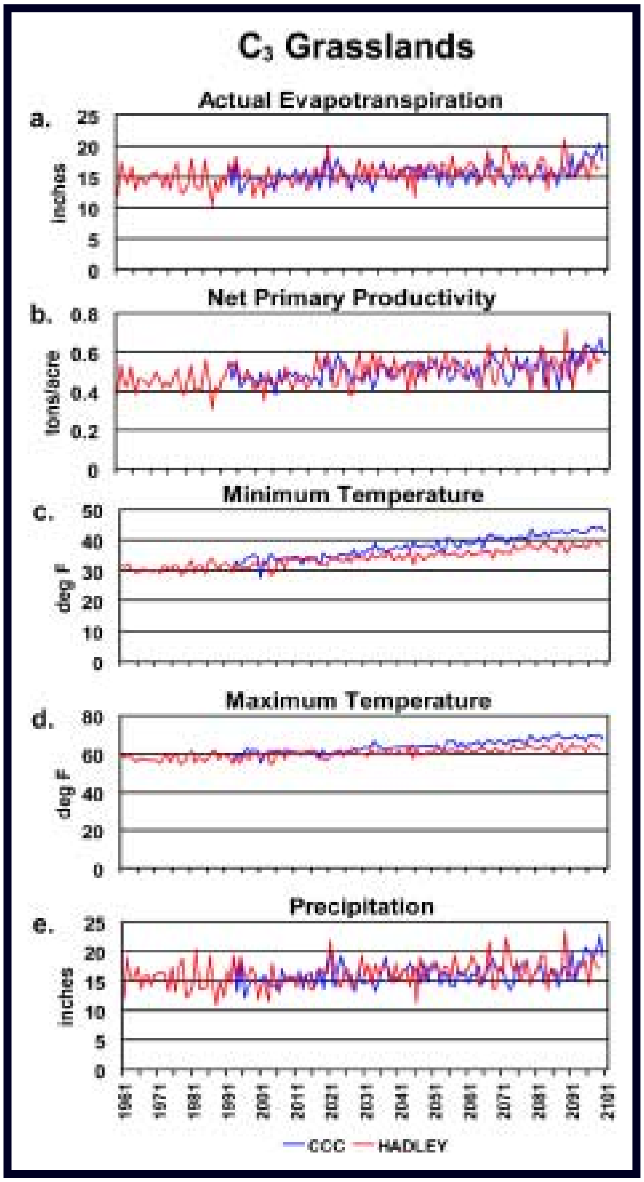


Fig. 3-2: Historical trends (1961-1993) and projections of trends into the future (1994-2099) in actual evapotranspiration (AET), net primary productivity (NPP), minimum temperatures, maximum temperatures, and precipitation in cool-season (C_3) grassland regions of the Great Plains. (Source: Kittel et al. 1997, Kittel et al. 2000)

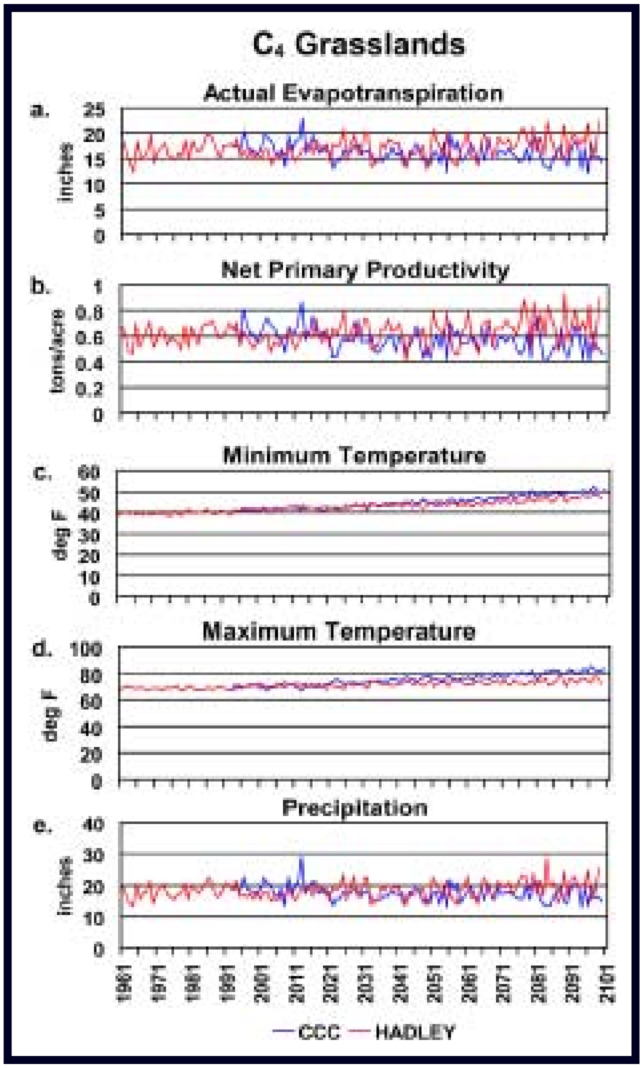


Fig. 3-3: Historical trends (1961-1993) and projections of trends into the future (1994-2099) in actual evapotranspiration (AET), net primary productivity (NPP), minimum temperatures, maximum temperatures, and precipitation in warm-season (C_4) grassland regions of the Great Plains. (Source: Kittel et al. 1997, Kittel et al. 2000)

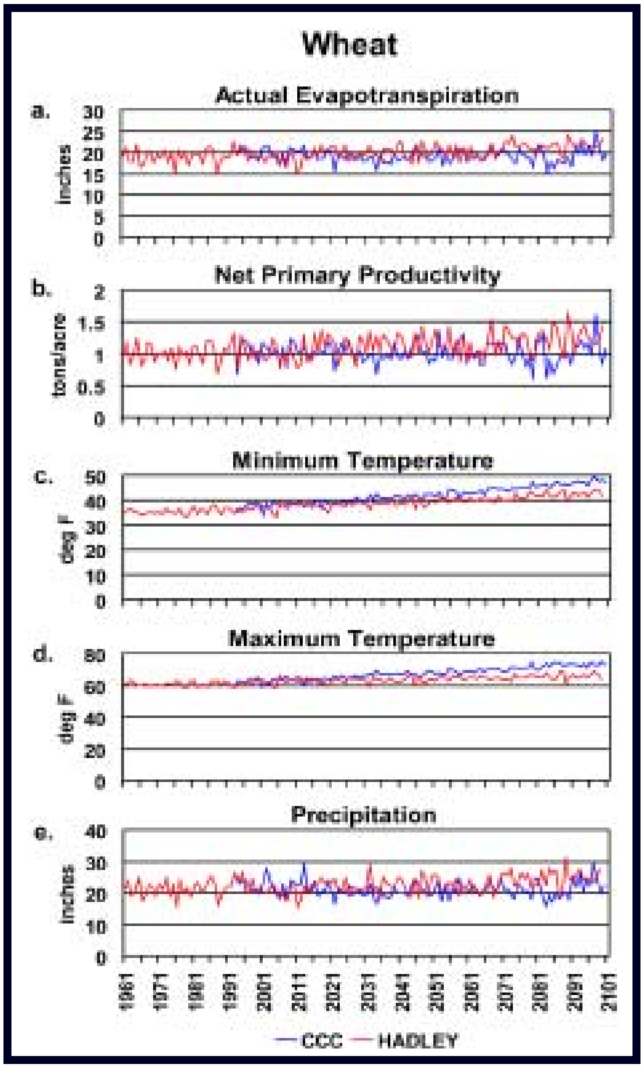


Fig. 3-4: Historical trends (1961-1993) and projections of trends into the future (1994-2099) in actual evapotranspiration (AET), net primary productivity (NPP), minimum temperatures, maximum temperatures, and precipitation in wheat regions of the Great Plains. (Source: Kittel et al. 1997, Kittel et al. 2000)

Table 3-1: Average actual evapotranspiration (AET) values for the 30-year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

AET (in/yr)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	15.79	17.20	16.14	18.35	17.32
Broadleaf	32.80	30.83	32.91	35.43	36.50
Mixed Forest	35.12	32.91	34.65	36.42	38.58
Savanna	22.28	22.64	23.35	22.68	24.09
Grasslands	14.88	14.96	15.67	16.30	16.73
Desert	12.48	13.90	12.68	12.64	13.74
Crop	22.36	21.93	23.23	24.53	25.28

AET (in/yr)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	16.10	17.60	16.61	19.33	17.60
Mixed Forest	15.43	16.61	15.63	19.53	16.10
Savanna	30.83	29.84	32.24	35.28	34.33
Grasslands	13.78	13.94	14.45	15.00	15.47
Crop	21.46	21.10	22.56	23.86	24.41

Change in AET with the two climate change scenarios indicated a close relationship to changes in precipitation during the scenario period (Table 3-2). The CCC scenario displayed a dramatic drying out during the first thirty years (1995 through 2030) which resulted in a greater proportion of the incoming precipitation to the grassland and cropland systems being used as AET. The trends are consistent with the overall pattern of changes in AET rates and relative water loss through evapotranspiration (ET) for changes in annual precipitation. Therefore, this region could be more vulnerable to water stress because the combined effects of temperature and precipitation could result in decreased water supplies.

Table 3-2: Average ratio of actual evapotranspiration (AET) to precipitation (PPT) for the 30-year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

AET/PPT (in/yr)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	0.80	0.83	0.78	0.80	0.74
Broadleaf	0.84	0.86	0.84	0.82	0.78
Mixed Forest	0.83	0.84	0.83	0.81	0.77
Savanna	0.91	0.91	0.90	0.87	0.87
Grasslands	0.92	0.94	0.93	0.92	0.91
Desert	0.96	0.95	0.97	0.95	0.96
Crop	0.86	0.89	0.85	0.85	0.80

AET/PPT (in/yr)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	0.71	0.75	0.68	0.72	0.63
Mixed Forest	0.71	0.76	0.66	0.76	0.59
Savanna	0.86	0.88	0.83	0.84	0.79
Grasslands	0.90	0.92	0.91	0.91	0.89
Crop	0.87	0.90	0.86	0.87	0.83

Water Supply

Population growth in the western Great Plains is already creating increasing water demands that will likely continue with climatic variability. Such increased demands for water have promoted innovative methods of increasing water storage, for example, through artificial groundwater recharge. There will continue to be increasing demands for water storage to maintain a sustainable water supply as populations increase and climate changes. Changes in the flow regime (because of climate changes) and the social acceptability of structural solutions to water containment and storage will require a reexamination of infrastructure and systems operations since recent water development has moved away from structural development solutions. Part of this movement comes from recent extreme events in the Great Plains (e.g., floods in North Dakota) that encourage the reevaluation of the current water impoundment structures.

Although some large federally-funded infrastructure projects may have been designed with excess capacity, which serves as a reserve in times of extreme precipitation or streamflow, many smaller, locally-funded projects do not have such excess capacity. Examples include reservoir capacity, height of dikes, and capacity of flood-diversion channels. Consequently, climate changes affecting precipitation levels and extremes could cause such systems to be unable to perform their water-holding functions, leading to increased stress on local resources from floods.

The scientific basis for determining water needs of aquatic ecosystems under current and climate change scenarios should be further refined. Aquatic ecosystems in the Great Plains face numerous existing stresses caused by the competing demands of agriculture (including water quality issues such as nitrogen runoff) and urban uses. Climate changes may place the aquatic ecosystems under additional pressure. Temperature and precipitation changes could have a wide range of effects on already vulnerable ecosystems. These effects could range from dry wetlands and stream beds, to extreme instream flow variability, to increased demands on water supplies from agriculture and urban/residential users. Warmer air temperatures may affect water temperatures and the increased ability of exotic/non-native species of pests, fish, and plants to migrate into Great Plains aquatic ecosystems and disrupt these already stressed systems.

Wetlands

Wetlands are also under significant stress throughout the world due to human activities, such as draining for agriculture and urban expansion. Globally, about half of all wetlands have been lost since approximately 1940. In the U.S., excluding Alaska, about 40-60% of wetlands have been lost, with percentages in some states, such as Ohio, as high as 90%. Wetlands in the Great Plains have undergone similar losses; in central Nebraska near the Platte River, most wetlands are gone. Changes in the timing, areal distribution, intensity or form of precipitation (rain, snow, hail, etc.), coupled with increased evaporation/transpiration rates, has the potential to affect biological/agricultural resources in the Great Plains. Already, regulation of streams and rivers have resulted in a change in the natural hydrograph (the measurement of surface waters of the earth as a function of time) reducing riparian habitat. Instream flow requirements important for biological diversity will increasingly compete with consumptive uses. Furthermore, problems associated with salinity and other pollutants in surface and groundwater will increase with an intensified hydrologic cycle.

Wetlands provide critical hydrological, biological, and biogeochemical functions, which have corresponding benefits valued by society. They provide flood control and water storage, assist in pollution filtering and waste processing, provide critical habitat and breeding ground for birds and other species, and assist in the global cycling of carbon and nitrogen. Any wetland loss or degradation that interferes with these functions would have corresponding effects on the benefits valued by society. In the Great Plains, prairie potholes have traditionally provided critical water storage and waterfowl habitat. It is estimated that prairie wetlands contribute to more than half of the annual waterfowl population produced in North America. The central section of the Platte River has provided both a source of food and protection for waterfowl and shorebirds during spring and fall migrations.

Wetlands may be affected by any changes in temperature, precipitation, and evaporation/evapotranspiration, which alter the water supply to the wetland through changes in runoff, streamflows, and groundwater recharge. Both the seasonal patterns and intensity of precipitation events are also important. In the northern prairies, if evapotranspiration increases and snowmelt runoff decreases as some scenarios project, a dramatic loss of meadow and shallow marshlands could result. Wetlands in the central flyway in Nebraska could be adversely affected by any drop in river water levels during migration periods. However, wetlands could be enhanced if increased precipitation exceeds evapotranspiration, so as to consistently provide increased streamflow and groundwater supply.

Prairie potholes are considered particularly vulnerable to climate change due to their inability to adapt through migration. This has been further exacerbated by human development and agriculture in surrounding areas. Riverine ecosystems tend to have a higher potential to adapt through natural or assisted migration due to the high degree of spatial and temporal variability of their natural environment.

Agricultural Water Management

Consumptive water use by agriculture involves both flood irrigation from surface waters, particularly in the western portion of this region, and spray irrigation derived from both surface water and groundwater. Management of both sources is a major task for this region, a task that will be burdened by any possible decrease in available water or any increase in temperature and evapotranspiration concomitant with climate change. Considerable water is drawn from riparian aquifers which can be recharged quickly through appropriate riverine management. More difficult to manage are the regional groundwater aquifers which are, to some extent, not rechargeable in the present climate regime. The most widespread and best known among these is the Ogallala Aquifer. There is a need to match the drawdown from the Ogallala Aquifer to the recharge from precipitation in order to avoid irreversible depletion of the water resource. Changes in precipitation and evapotranspiration demand may lead to changes in recharge and drawdown respectively.

Use of surface water for irrigation is another water management issue. More efficient application methods (water pulsing, etc.) could decrease water needed. Water availability in dryland systems and irrigated systems can both be affected by residue management and tillage practices.

Quantity of water available for particular uses depends on political/social/economic means of allocation and control. Water quality is compromised by salinity and runoff of fertilizers and wastes. Pressures for more high quality water stresses regulatory and decision mechanisms. These stresses will be exacerbated if climate change reduces water availability.

In addition to water quantity issues, further research is needed to help determine the effects of climate change on water quality and ways to best correct and mitigate water quality problems. Changes in land use and climate will affect water quality; for example, knowledge of how to best manage livestock wastes during extreme precipitation events is needed. Salinity management is an important issue in certain areas of the Great Plains. Rivers become more saline due to runoff and percolation through highly saline soils. High salinity affects crop production and adversely impacts fish and wildlife habitat. Drinking water quality in the Great Plains is also an important issue. Many small towns struggle to meet current drinking water standards. Non-point source pollution can contain contaminants from fertilizers, herbicides, pesticides, livestock wastes, salts, and sediments that reduce the quality of both surface water and groundwater drinking water supplies.

Changes in climate may also affect the numbers and types of pests. Pest control operations have the potential to affect water quality as water drains through crop fields. Deterioration in water quality could have additional adverse impacts on the ecosystem.

Agricultural and Biological Resources

The condition of the plant communities in the Great Plains is important to the agricultural and ecological well-being of the region. Livestock and wild fauna depend on the natural vegetation. The amount and composition of the vegetation is also a key concern to ranchers, farmers, and conservationists alike. Land uses and demographic changes within the region are affecting the decisions of how to manage the plant communities. These interactions are also impacting the number and the rate of spread of invasive (non-native) species throughout the Great Plains. Changes in the natural vegetation and other environmental factors are changing the biodiversity of the region and affecting pests, disease incidence, and other undesirable species.

Regional change in climate variability and extreme events will affect various aspects of agricultural systems and people in the Great Plains. First, changes in winter moisture and temperatures may be advantageous to cool season invasives, increase the extent of sagebrush and other woody perennials on the range, and allow certain disease vectors to persist longer. For example, leafy spurge and Japanese brome may move further south, and sagebrush may move further east. In addition, warmer wetter winters may increase decomposition rates resulting in additional losses of soil organic matter. Second, summer increases in temperature and precipitation may impact hail events, the encroachment of invasive trees, and fire management. If increased productivity, that may result from the altered system of temperature and precipitation, is followed by drought, there may be problems with fire due to increased fuel. With more moisture coming in heavy downpours, there may also be more lightning from convective storms leading to fires. Third, a change in the frequency and duration of extreme events can lead to the opposing problems of drought and deluge, and early fall and late spring snow storms which can bring problems all their own. The extent to which the ranching and livestock sector will be affected is uncertain, and will be determined by the regional extent of climate changes. The response of the natural resources, including vegetation, soil, water, and fauna, will need to be examined as an integration of the feedbacks between these resources.

These potential changes to the vegetation and water resources in the region will have a large impact on grazing systems. These include direct impacts, such as crop/livestock thermal and water stress and the CO_2 effect on range production (both on individual plants and plant communities) and indirect impacts, such as the possible change in pests, diseases, and weeds.

Plant Productivity

Simulations of plant productivity under current climate conditions and under GCM derived climate projections were produced using the Century ecosystem model (Parton et al 1994, Ojima et al. 1993). The simulations were conducted in cooperation with the VEMAP contribution to the National Climate Change Impact Assessment (VEMAP, 1998, USGCRP 2000, Schimel et al 2000). The climate change impacts on the overall plant productivity of the various ecosystems in the region had minor effects (Fig. 3-5a-f). Both the CCC and Hadley GCM scenario results indicated that an increased level of plant production was observed after 100 years (1994 to 2100, Table 3-3). There was a slight depression in productivity simulated during the first 30 years of the CCC scenario due to drier and warmer conditions occurring over the region, but these ecosystems recovered in subsequent years (see Fig. 3-2b, 3-3b, 3-4b). The time trends of plant productivity for grassland and winter wheat ecosystems closely follow precipitation trends for the two climate change scenarios (see Fig. 3-2b, 3-3b, 3-4b). The plant responses to increasing levels of carbon dioxide in the atmosphere compensate for the climate warming and may contribute to the higher than expected increase in productivity over the region.

Figure 3-5 (a-c): Net Primary Productivity 2025-2034 (tons/acre/yr)

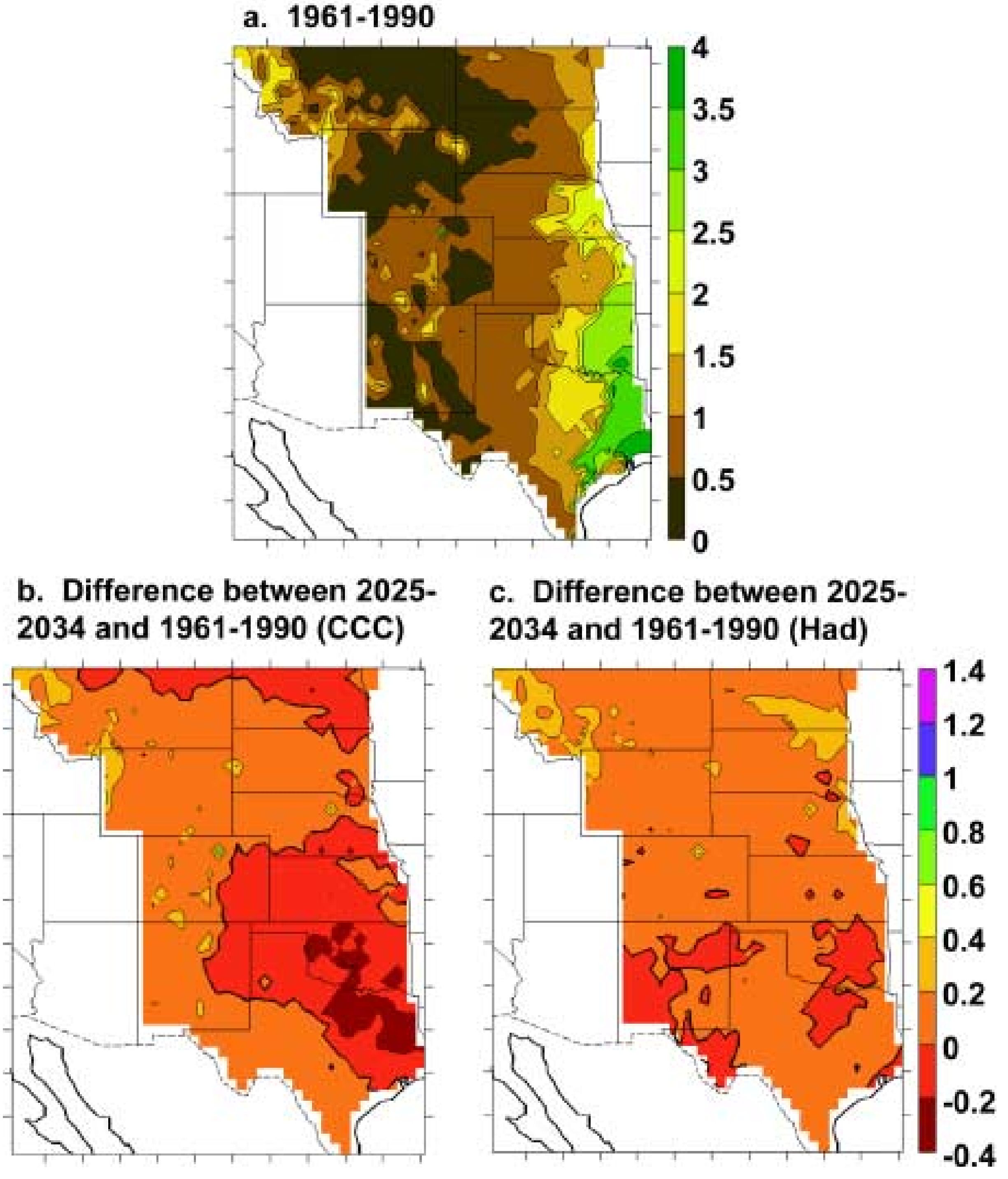
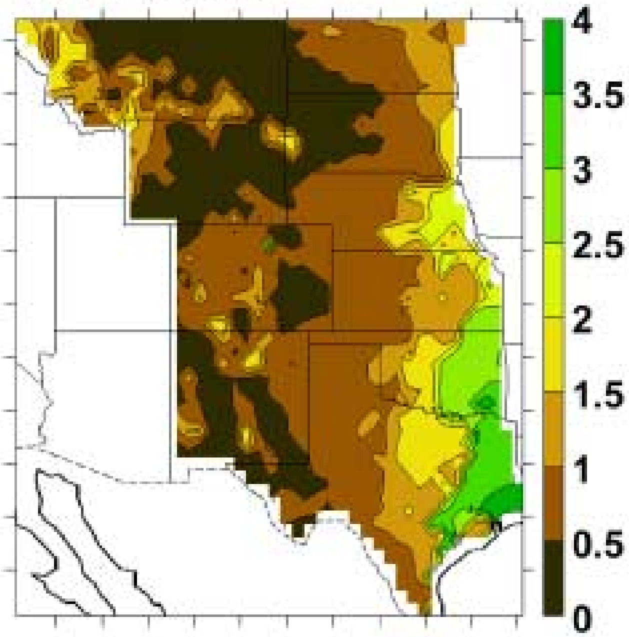


Fig. 3-5: Average historical net primary productivity (1961-1990) and model projections of average changes in NPP in the future (2025-2034 and 2090-2099). At 2030, the CCC model shows the largest decreases in NPP over parts of Oklahoma and northern Texas (panel b). This corresponds to the increase in temperature and the decrease in precipitation projected in this region. At 2090, besides a slight decrease in NPP over the panhandles of Texas and Oklahoma, both models project moderate increases in NPP over the region (panels e and f).

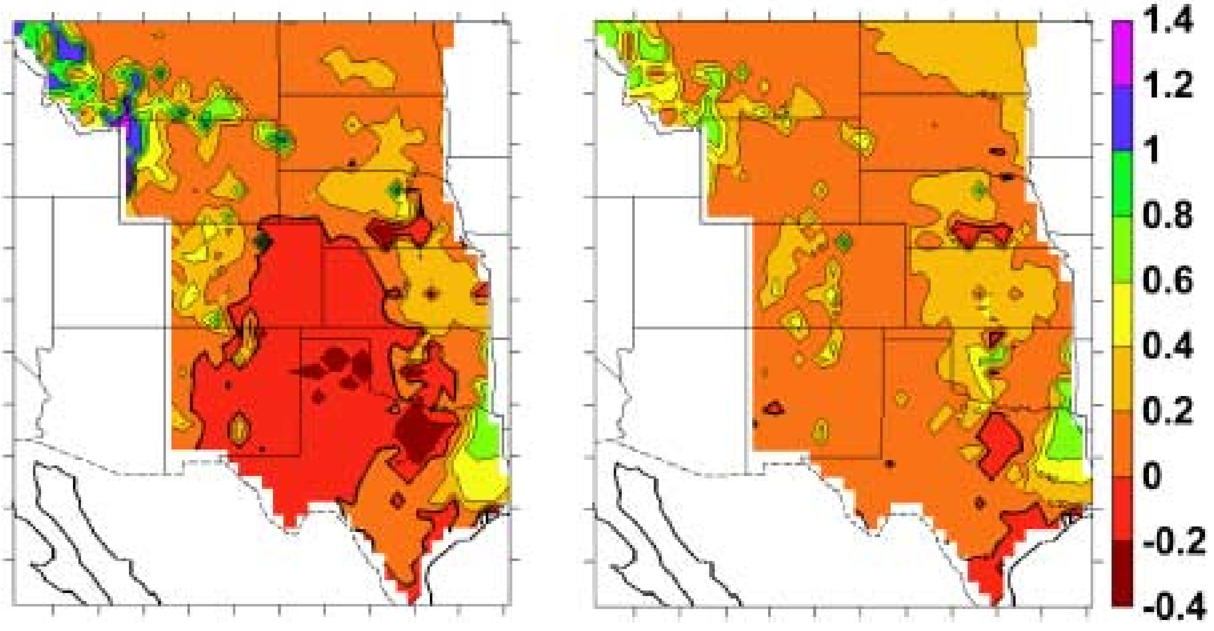
Figure 3-5 (d-f): Net Primary Productivity 2090-2099
(tons/acre/yr)

d. 1961-1990



e. Difference between 2090-2099 and 1961-1990 (CCC)

f. Difference between 2090-2099 and 1961-1990 (Had)



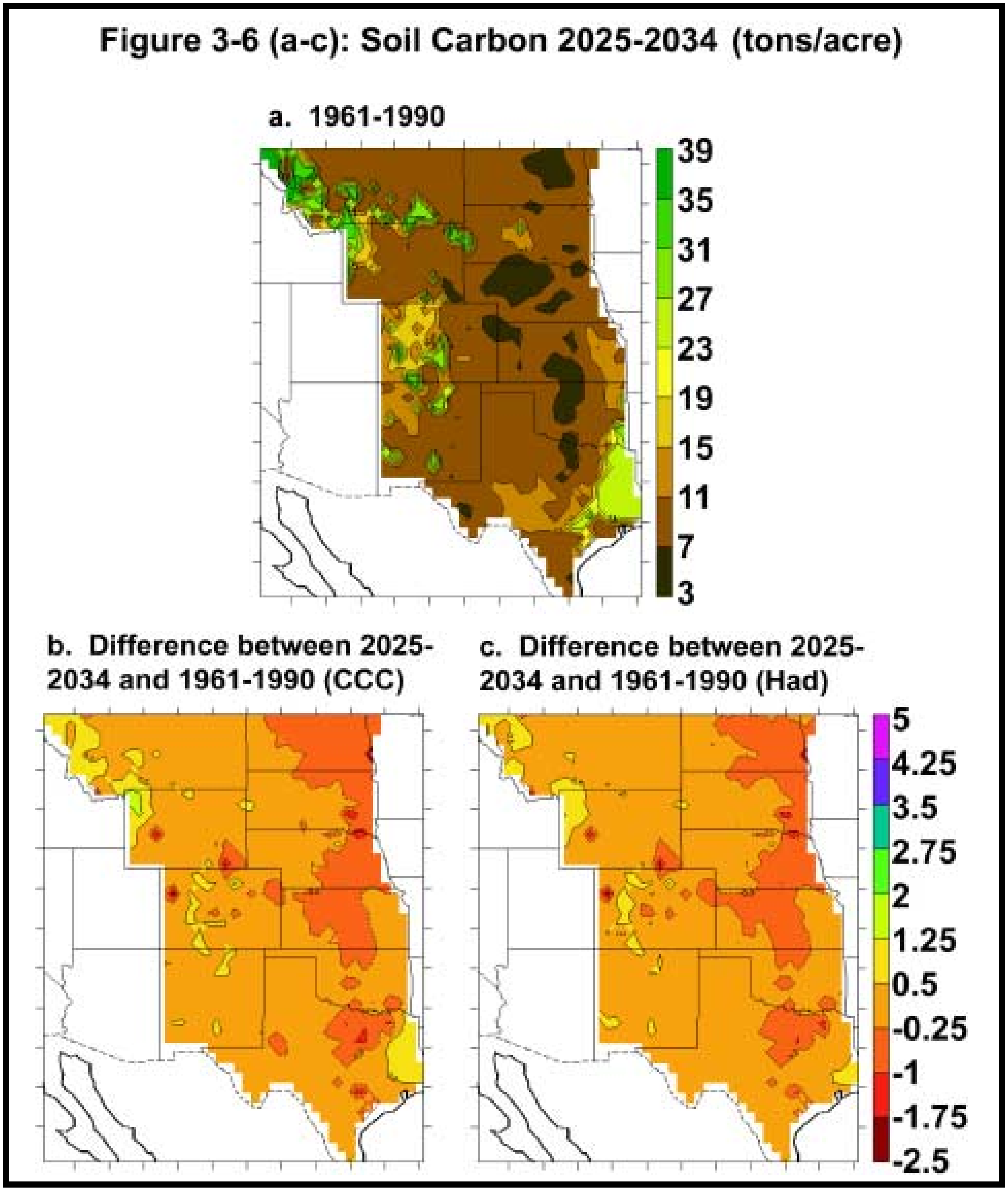
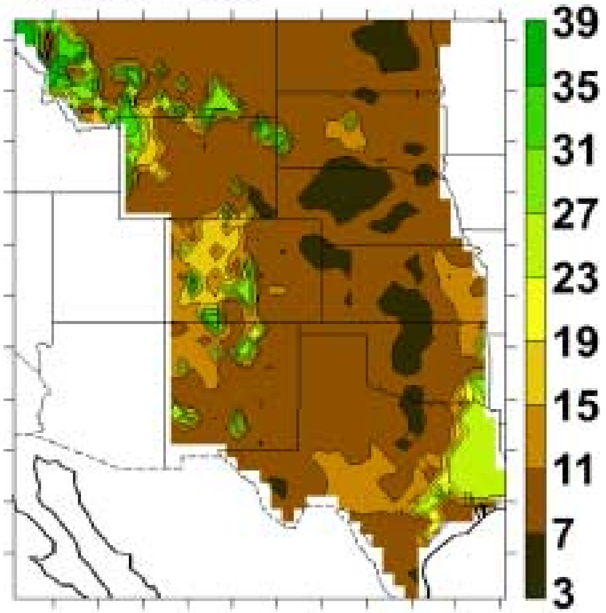
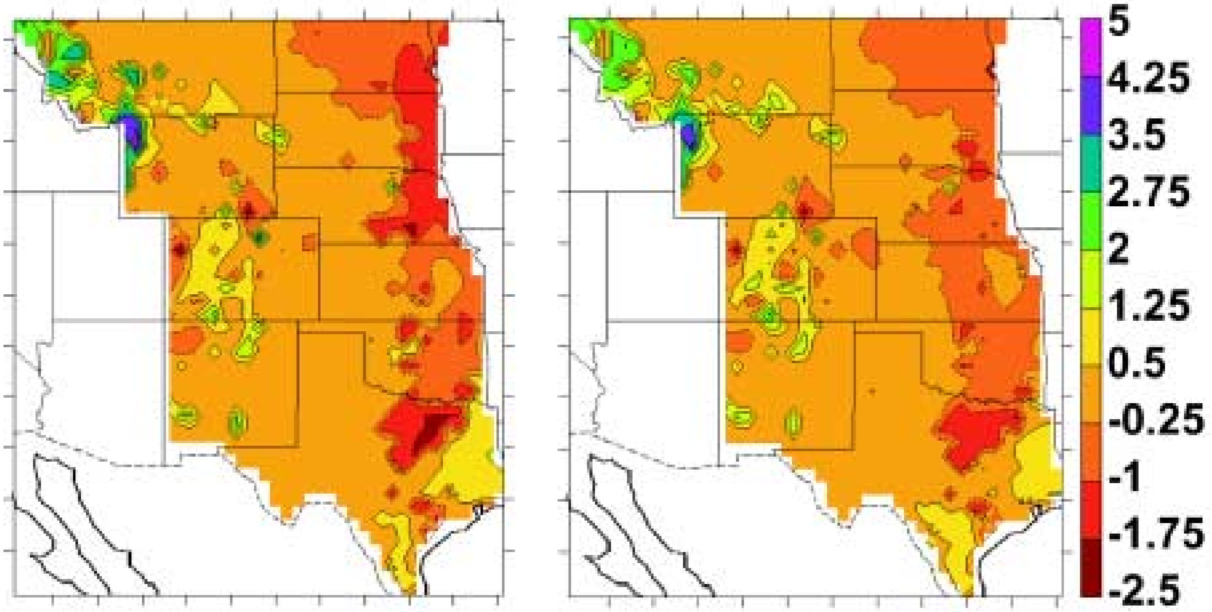


Fig. 3-6: Average historical soil carbon (1961-1990) and model projections of average changes in soil carbon in the future (2025-2034 and 2090-2099). Over most of the region, in both time periods and for both model experiments, the soil carbon remains relatively stable into the future (panels b-c and e-f).

Figure 3-6 (d-f): Soil Carbon 2090-2099 (tons/acre)



d. 1961-1990



e. Difference between 2090-2099 and 1961-1990 (CCC)

f. Difference between 2090-2099 and 1961-1990 (Had)

Table 3-3: Average net primary productivity (NPP) values for the 30 year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

NPP (tons C/acre/yr)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	0.99	1.14	1.08	1.37	1.26
Broadleaf	2.94	2.82	3.06	3.41	3.37
Mixed Forest	3.01	2.86	3.07	3.48	3.47
Savanna	0.98	1.02	1.04	0.98	1.08
Grasslands	0.50	0.52	0.55	0.56	0.60
Desert	0.44	0.50	0.43	0.40	0.49
Crop	1.51	1.45	1.60	1.59	1.70

NPP (tons C/acre/yr)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	1.01	1.21	1.13	1.49	1.33
Mixed Forest	0.76	0.80	0.74	1.11	0.95
Savanna	1.45	1.44	1.53	1.81	1.74
Grasslands	0.47	0.50	0.51	0.54	0.58
Crop	1.29	1.27	1.37	1.43	1.50

Soil Resources

Diminishing soil fertility over the last 10-20 years is currently a great concern for this region. The practice of long fallow periods with tillage (preparing soil for planting by plowing) has contributed to these soil organic matter losses. The cropping practices over the last 60 to 80 years have resulted in a decline of 50% of the soil nutrients and increased CO_2 release (Parton et al. 1987, Cole et al. 1988, Burke et al. 1994). With current economic conditions, summer fallow wheat is not profitable in the western region of the Great Plains and is only economically viable because of government support. This support, however, is being phased out allowing farmers more options for making their own land-use decisions.

Regional soil carbon changes based on the two climate change scenarios indicate that eastern and western portions of the region will likely lose soil organic matter due to changes in decomposition rates brought about by warmer temperatures (Fig. 3-6a-f). The central portion of the region will likely gain soil carbon, despite the increase in temperature, which is most likely due to reduction in the decomposition rates resulting from the lack of soil moisture needed for microbial activity.

The land has suffered because of a historical emphasis on feed grains. Government policy has favored support of feed grains and has not promoted alternate cropping systems which are water and soil conserving. Soils which are less degraded and have higher organic matter content hold more water and nutrients. A potential solution to the loss of soil fertility is high-residue, high-tech farming (e.g., non-tillage systems) which is more water efficient in irrigated and rain-fed systems. Despite the increased demand for feed grains in support of the livestock demands, dryland cropping should be able to meet the challenge.

Soil is viewed as a critical resource that maintains the agricultural system of the region. Fertile and organic matter rich soils maintain a high level of production of pasture and crops despite the semi-arid nature of the region. Additionally, soil is also a resource which if properly managed will lead to potential mitigation options for long-term storage of carbon and additional benefits to the ranchers and farmers of the region. The people living in the Great Plains view the soil as a resource needing protection and a resource made vulnerable to climate changes given the increased human-induced perturbations that have taken place.

Simulated soil organic matter level estimates under the two climate change scenarios showed little change during the 100 years of the climate change scenarios (Table 3-4). This is indicative of the maintained levels of plant productivity resulting from these same climate scenarios. The simulation projected slightly greater levels of soil organic matter for the central region of the Great Plains (e.g., Colorado, Wyoming, Nebraska, and Kansas) (Table 3-4).

Table 3-4: Average soil carbon (SOIL C) values for the 30 year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

SOIL C (tons C/acre)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	20.93	21.36	21.32	21.92	22.00
Broadleaf	25.22	25.52	25.40	25.98	25.61
Mixed Forest	22.63	23.17	23.03	23.56	23.28
Savanna	10.20	10.34	10.32	10.56	10.55
Grasslands	9.07	9.05	9.02	9.12	9.04
Desert	9.68	9.69	9.73	9.89	9.83
Crop	8.22	7.82	7.88	7.55	7.68

SOIL C (tons C/acre)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	22.04	22.60	22.54	23.26	23.43
Mixed Forest	9.94	10.05	10.13	9.67	10.03
Savanna	12.56	12.85	12.87	12.53	12.62
Grasslands	9.12	9.11	9.07	9.14	9.06
Crop	7.85	7.48	7.50	7.40	7.40

Research Needs

Current understanding of the needs of aquatic systems for survival under current demands and climate is incomplete. Water apportionment decision-making between aquatic ecosystems and human uses needs to be more clearly assessed. We have only begun to evaluate the effects that projected climate changes would have on water resources and the subsequent impacts these changes would have on Great Plains aquatic ecosystems. These impacts are made more complicated due to anticipated greater urban demands for water resources in the future.

Changing climate patterns can also cause changes in habitat extent and species mixtures for crops and livestock activities. As climate changes, an expansion of weeds and pests could occur. Understanding what effects exotic (non-native) species will have on habitats and how climate change will affect invasibility of different habitats by non-native species needs to be researched further. The impact of climate change on biodiversity and habitat change also needs to be better understood and assessed.

Agricultural and rangeland ecosystems play an important role in soil conservation and land management. Agricultural management has produced beneficial systems incorporating the use of grass/legume mixtures in dryland crop rotations, different cropping systems to improve soil carbon levels and reduce trace gas emissions, improved water management, and integrated farming analysis to evaluate changes in farm management and conservation of natural resources. These efforts need to be extended relative to changes in climate in different regions of the Great Plains.

Assessment is needed of rangeland ecosystem relationships to livestock dynamics, and invasive species relative to rangeland health. The role that the diversity of both plant and animal components of rangeland ecosystems play in maintaining good rangeland health needs to be evaluated. Studies of climate change and CO_2 changes on the vegetation and animal dynamics need to be evaluated relative to the ecosystem level response to these changes. Evaluation of various management strategies for coping with climate change, including alteration of changes in the frequency and intensity of grazing, is needed to develop strategies that promote sustainable rangeland use.

The role of disturbance in modifying ecosystem and habitat characteristics resulting from climate change and other human perturbations needs to be evaluated in a more integrated context with scenarios of not only climate change, but also including consideration of land use practices. The human-induced changes to the natural systems related to the extraction of coal, gas, and other mineral resources which impact water, air, and land resources, need to be explored. The impact of these changes to ecosystems and how they may be reclaimed under a changing climate needs to be evaluated.

STAKEHOLDER IDENTIFIED CRITICAL IMPACTS

There were many potential impacts of climate change in the Great Plains identified by the stakeholders in the region. Many identified the modified vulnerability of farm/ranch families to climate and market stresses as an impact. This means there will be winners and losers from climate change, depending on the direction of the change and the adaptations employed. Next, crop and livestock production will likely be modified, possibly including changes in breeds or species. Further, water use competition will be impacted by climate change and variability, as will water quality. There could also be an expansion of weeds, pests, and diseases. These could affect production and will require community involvement for their control. There will be changes in plant and animal communities and interactions, and fire and storm patterns could be altered. This has important implications for natural resource management and human settlement patterns.

Additionally, when looking strictly at range and livestock systems, other potential impacts were identified. First, forage production and quality will certainly be altered. Some of the changes may be beneficial, such as enhanced production under elevated CO_2, while other changes may be deleterious, such as the fact that the forage will likely be less nutritious. Carrying capacity will be impacted and there will be vegetation shifts. Increased extreme events could lead to impaired performance and health of intensive livestock systems if livestock thermal thresholds are exceeded. There could be changes in the irrigation water supply, which has implications for the raising of feed for livestock. Also, because warmer temperatures lead to increased decomposition, there could be declines in soil organic matter due to a warmer climate, although there are other factors which influence soil organic matter levels, including precipitation rates. There could be an increased rate of aquifer use and loss of wetlands for waterfowl due to increased temperatures in the region.

Related to these concerns are issues such as stability of food production and information transfers. Agricultural production is affected by external factors related to market prices, crop production in other regions, and the cost of inputs. Current production systems are more variable due to changes in market prices and inherent environmental variability. The use of specialized varieties may also contribute to the variability of crop yields when weather patterns in a local area are atypical.

Related to all of these impacts discussed above are varying levels of uncertainty related to the actual outcome of a changed climate. Many of these uncertainties will be addressed, along with the identified potential impacts, in the remainder of the report.

IMPACTS: CHALLENGES AND OPPORTUNITIES

SECTORAL GROUP REPORTS

Impacts: Challenges and Opportunities

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Sectoral Group Reports

The following five chapters contain the reports from the break-out groups at the March 1999 Sylvan Dale workshop for the Central Great Plains Climate Change Impacts Assessment: water, cropping systems, ranching and livestock, and conservation/natural areas. Additionally, Chapter 8 reports on the cross-cutting issues which were discussed at the workshop.

These chapters are organized in similar ways, but differences may be attributed to the fact that the reports were compiled by different authors at the completion of the March 1999 workshop. They capture what was discussed at the workshop related to climate change effects and possible coping strategies for each sectoral group.

Many people are unwilling to plan for climate change now because they may believe that the science is not completely certain at this point. The Precautionary Principle, suggested as a policy to guide international environmental negotiations, suggests that: "Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (Bergen Ministerial Declaration 1990). Following from this principle, the risk management solutions identified in the following chapters will be beneficial to land managers whether or not the GCM scenarios reflect the correct future climate, and whether or not there is a dramatic climate change in the near-term. Many of the techniques and coping strategies are tried and proven practices that have been used historically to deal with climate variability and need little or no research to be implemented with great benefit for land managers.

CHAPTER 4:

WATER REPORT

Water Report

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Introduction

A number of diverse groups vie for water within the Great Plains region. The competing uses include agriculture, urban and domestic, industry, recreation, wetlands, and in-stream habitat. Within each state in the region, the allocation of water among uses depends on the ownership of water rights, and on the contracts and operating rules governing federal and other public water projects. Initial allocations can be modified by market transactions, but the cost of transferring water or water rights through markets varies considerably from state to state, and legal restrictions on transfers from agricultural to non-agricultural uses have not yet been eliminated in all states in the region. The allocation of surface water between states is governed, in many instances, by interstate compacts. However, these agreements have been subject to costly litigation. Interstate lawsuits or legal arguments are ongoing in both the Platte and Arkansas River basins.

Water needs and available resources differ across different agricultural groups as well as within each group. This leads to differences in sensitivity to particular climatic changes, such as an alteration in the seasonal pattern of precipitation. Three distinct types of agricultural production systems were identified: 1) crop/fallow or non-irrigated agriculture, 2) groundwater irrigated, and 3) river valley irrigated. Each of the three systems is a distinct type of resource use, resulting in considerable variation within each system.

The productivity of the crop/fallow system or non-irrigated agriculture is directly dependent on the prevailing climate patterns. The crop/fallow or non-irrigated agricultural systems are based on the concept of using the root zone as a reservoir in which the limited amounts of precipitation are stored as soil water. Changes in the quantity and distribution of precipitation as well as changes in temperatures will affect the viability and productivity of this type of system. Groundwater irrigated systems rely mostly on the amount of water available in underground aquifers. The rate at which these aquifers are depleted and the application efficiency of the systems are also affected by climate. The river valley irrigated systems in this region are heavily dependent on snowmelt from the Rocky Mountains. Thus, an evaluation of the effects of climate change on the Great Plains must include estimates of changes in mountain snowfall and the associated runoff. Both irrigated lands and agricultural land not currently irrigated may compete for scarce water resources in the future, depending on potential climate changes.

Long term climatic changes could have very profound effects on the region and on the identified groups and could, furthermore, change the extent to which the various groups of water users compete with one another for available supplies. Users of water and related resources will need to find coping strategies within the context of changing patterns of water availability and changes in the desired water uses of other parties.

In order to understand potential climate change impacts, consideration of critical water resource issues within the region and the associated implications for adaptation to the effects of climate change is needed. These issues and adaptive strategies can be examined in light of particular climate change scenarios. Identifying impacts and coping strategies for various groups of water users, and users of related resources, within different portions of the Great Plains region given these scenarios can then be evaluated. The next section discusses water concerns by identifying critical issues, scenarios, and coping strategies.

Critical Issues

1) Managing the effects of climate variability/adapting to climate change in the long term

Current management of climate variability focuses on maintaining the ability to cope with historically experienced extremes. For drought, the Northern Colorado Water Conservancy District uses the 1950s drought as a standard in its planning and storage operation decisions. The question arose as to whether this approach would be sufficient to handle the effects of global warming. The group also questioned how well we could actually deal with the 1950s drought under current laws. For example, how would we accommodate Platte River endangered species concerns? If droughts became more frequent, problems would arise with declining aquifer levels, as there would be less recharge due to infrequent rains and possibly increased use for irrigation. This could affect Colorado's ability to use groundwater recharge and storage as one of the means to meet South Platte Compact obligations.

Our present methods for managing the impacts of climate variability may need to be modified if climate change has significant impacts on total snow cover and the timing of the spring melt. For example, for one of the scenarios provided, there would be a 5.4-7.2° F (3-4° C) warming, and less total snowpack and earlier snowmelt. This would result in an earlier peak in the annual hydrograph (the measurement of surface waters of the earth as a function of time) and lower late summer flows at critical points where a certain amount of water must be delivered by law, such as at the Colorado/Nebraska border. To some extent, artificial groundwater recharge operations could be used to re-regulate the flow to maintain late summer streamflow at the state-line.

As for flooding, flash floods that result from intense rainstorms, such as the storm in Fort Collins, Colorado in 1997, are a major problem in this region. It is important to understand the extent to which climate change might affect the frequency of such events. A potential coping strategy would be to increase the buffer around floodplains, in order to limit development in floodplain areas. The buffer could be increased from the 100 year event as the criteria for defining the floodplain, or the 100 year event could be redefined. This is possible but could be very costly.

2) Laws and other institutional factors

Flexible institutions would help to mitigate the adverse impacts of climate change. Most states in the region allow willing buyers and sellers to exchange water rights or to sell water on a short-term basis. This can enable high value uses to obtain water during drought emergencies or when needed for growth. However, there are legal impediments to moving water between different types of uses. Nebraska, for example, does not yet allow for agricultural water rights to be transferred to another type of use, and is only just beginning to consider legislation to allow for such changes.

Other issues are concerned with the relationship between state primacy over water allocation and broader national concerns. The appropriate balance between federal and state control is an ongoing question that will have implications for efforts to plan for and adapt to climate change. A prominent example here is the ESA (Endangered Species Act) and its requirements for the development of recovery plans for listed endangered species. Flexible institutions are seen as possible coping strategies to lessen water disputes between state and federal water users.

Water banking is a relatively new concept in the region that may provide increased flexibility. Water banking includes various arrangements designed to increase the reliability and/or value of the water supply by moving water-use from times or types of uses in which its value is relatively low, to times or uses in which it is more valuable. The term "water banking" is applied to two distinct types of arrangements: 1) "groundwater storage banks" may involve active recharge of aquifers, or a current reduction in groundwater pumping in order to provide increased groundwater supplies for later withdrawal; 2) "water transfer banks" provide a formal mechanism to facilitate voluntary short-term transfers of the use of water under existing rights. Kansas, for example, is developing a water banking program. In some cases, municipalities have acquired water rights in advance of need and are currently renting them back to agricultural users. This practice may provide a drought buffer for the urban uses.

3) Population growth and urban development plans

The region's population is growing and is becoming increasingly urban. This has led to a change in the nature of water demands in the region, with agricultural to municipal water transfers becoming an increasingly common way of meeting growing urban water demands where possible. Agriculture, however, remains the dominant water user in the Central Great Plains and the larger Great Plains region.

Climate change could have implications on long-term planning for urban development and water use. For example, if there is a change in the amount and timing of water there may be a decline in the reliability of water supplies available to holders of junior water rights at certain times of the year. People with junior water rights may only use water after people with senior water rights take the water that they need. Cities now served by relatively junior rights might want to re-evaluate their water rights portfolios and consider firming up their supplies. Attention could also be given to managed groundwater recharge, a concept that is being undertaken by the city of Denver, Colorado. This provides "environmentally acceptable storage," and serves as a viable alternative to unpopular new surface storage projects such as the rejected Two Forks Dam. In addition, the need for new sources of supply could be reduced through conservation, xeriscaping, and the use of gray water systems for landscape uses. Urban uses are not currently very consumptive compared with other uses. That fact provides some flexibility for drought management agreements with downstream senior agricultural users. Any significant change in the proportion of urban water that is consumptively used may require compensation to downstream right holders, however.

4) Lawsuits

This region is embroiled in interstate lawsuits over water allocation, as well as separate actions regarding endangered species or bypass flow requirements at dams located on federal lands. Litigation is a costly way to resolve conflicts. In addition, the resulting decisions are unlikely to prepare us for climate change because they tend to "set things in concrete" rather than create flexible institutions for adapting to unanticipated hydrological changes. While the winners in such suits will be in a better position, the losers will have to be even more serious about developing coping strategies. But, as conditions change, what previously might have been viewed as desirable could become the opposite, and if legal constraints do not allow flexibility this could create problems even for the perceived "winners" in previous litigation.

Climate Scenarios

The use of scenarios to evaluate possible implications of relevant climate changes not based on GCM results, but on critical aspects of the water system in the region, is a useful way to identify vulnerabilities to specified hypothetical climate changes. Accordingly, a set of four climate change scenarios based on: a) the contribution of mountain snowmelt runoff to surface water availability and b) the timing and total amount of growing season precipitation are presented here. In all cases, it was assumed that temperatures during the growing season would be warmer.

The current climate in the region is characterized by peak precipitation occurring in June, while peak crop water use (and therefore irrigation demand) occurs in July and August. Moving eastward from the Front Range of the Rocky Mountains, annual precipitation increases approximately 1 inch (25.4 mm) for every 50 miles (80.5 km). As a result, agriculture at the western boundary of the region is more dependent on irrigation than on growing season precipitation, while precipitation is the primary water source for agriculture in the eastern part of the region. The group focused on the following scenarios:

> Scenario # 1 – historical snowmelt runoff; historical precipitation amount, but coming two months earlier (peaking in April and May)
>
> Scenario # 2 – historical snowmelt runoff; historical precipitation amount, but coming two months later (peaking in August and September)
>
> Scenario # 3 – historical timing of snowmelt and precipitation, but more total snow and growing season precipitation
>
> Scenario # 4 – historical timing of snowmelt and precipitation, but less total precipitation and snowmelt runoff

The discussion of these scenarios is outlined in Appendix D, although one scenario is highlighted here (Scenario 1). This was deemed to be the most likely scenario. In Scenario 1 the precipitation comes early, in April and May, although the amount is normal. General critical issues that would stem from normal amounts of early precipitation include: a longer growing season due to warmer temperatures, alluvial aquifer recharge, increased flow in rivers (especially in the early season), more spring runoff, and less evaporation because the soil would store more water. A general coping strategy to deal with Scenario 1 is to enhance the storage of water for later use, including using dryland tactics such as stubble mulch and no-till on irrigated land. Additional discussions of Scenario 1 including issues and coping strategies related to irrigated and dryland agriculture, urban areas, recreation, and power production are included in Appendix D.

Scenario #4 was deemed to be the most problematic, not only for agriculture, but for the entire set of regional water uses. The group noted that the impacts of these scenarios and the available coping strategies would differ between the eastern and western sections of the Great Plains. The entire suite of water sources (surface water, ground water, and growing season precipitation) along with surface storage reservoirs and ground water storage capacities must be taken into account to identify impacts and coping strategies. Of particular significance will be changes in soil water availability at the beginning of the growing season. That will determine the desired amount and timing of irrigation water applications and the availability of water for other uses, including artificial recharge of aquifers.

Coping Strategies

Some of the possible coping strategies for dealing with current drought periods, chronic water shortages, extreme weather events, and inter-annual climate variability were discussed in the context of their ability to help compensate for climate change impacts. These include: switching to crops that use less water; retiring marginal lands; adoption of conservation tillage methods; better watershed forecasting (watershed management models incorporating snowmelt and storm runoff); enhanced groundwater recharge activities; national forest management (patch cutting of the forests could enhance runoff from the mountains); and cloud seeding. The group concluded that the effectiveness of such measures and distribution of impacts across various water users would depend on a number of both natural and institutional factors. Reduced consumptive use of water in one location may simply allow increased diversions by other users, so there may be little or no net increase in the amount of water available for other uses, such as, instream environmental purposes. The water in the region's major rivers (such as the South Platte) is diverted over and over again, with each diversion entailing partial consumption. Return flows are often degraded in quality, so repeated diversion and rediversion of water from the South Platte River may create water quality problems. A change in irrigation practices is sometimes labeled "more efficient" if it reduces the ratio of water diverted (and return flow) to consumptive use. A change by an individual to these "more efficient" practices could improve downstream water quality by reducing the volume of contaminants leached from the irrigated field. The aggregate effect on water quality of a general switch in such practices is difficult to predict and will depend on the extent to which changes in the timing of return flows allow total diversions and total consumptive use to increase. If "more efficient" use also entails reduced consumptive use at each irrigation operation the impact on water quality would depend on whether any of the surplus remains in the stream to provide dilution or whether it is merely absorbed by new diversions and their associated consumptive uses.

In the discussion of coping strategies, it was noted that water management, particularly in the context of planning for adaptation to climate change, is a classic case of decision-making under uncertainty. Some of the principles identified in the literature to guide policy making in such cases are highly relevant here. When making decisions under uncertainty, one should:

- Diversify, in order to improve resiliency;
- Take a step and evaluate the consequences;
- Make decisions as reversible as possible;
- Design policies to open options, not close them;
- Avoid centralization to provide flexibility at the local level; and
- Create buffers, e.g. by buying and retiring water rights.

Research Needs

There were several future research needs or "action items" identified by the water group in order to truly understand the impact of climate change on the water sector and to cope with these possible changes. These include:

- Better information and information dissemination regarding climate change to stakeholders
- Better forecasting and preparation for extreme events, such as hail
- Flexibility in legal systems/institutions (flexible = adaptive) – locally tailored, but regionally coordinated and balanced
- Two-way communication between experts, the general public, and resource managers
- Identifying different needs at different times and locations (Front Range depends on snowmelt, whereas the eastern Great Plains depend more on spring rains)
- Coordination between state and local governments (water rights)
- Mission-driven research
- Decision-support tools

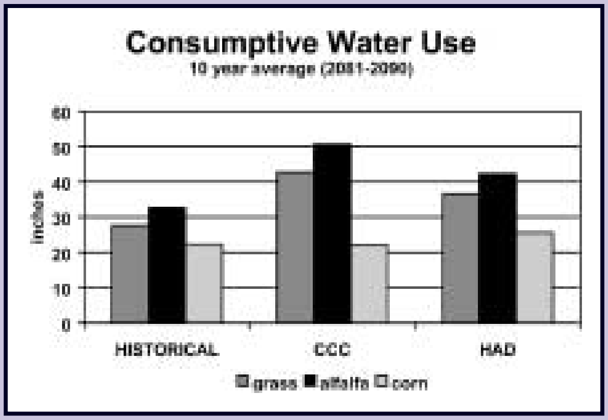
WATER STORAGE LOCATIONS UNDER A CHANGED CLIMATE

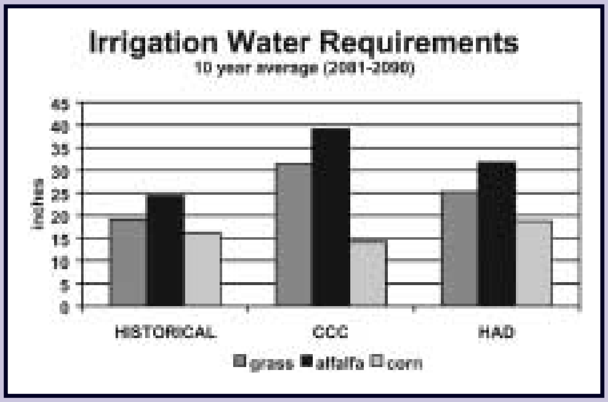
The assessment of Scenario One (see discussion on previous page) as relatively less problematic for the central Great Plains region is not intended to imply that there will not be significant regional or sectoral impacts. For example, a change in the seasonality of precipitation and high elevation runoff could have a significant impact on many water management activities in the western part of the central Great Plains. Current water resource management along the eastern edge of the Rocky Mountains depends on the storage of winter precipitation as high elevation snowpack well into the growing season. The snowpack acts as a natural reservoir storing water seasonally at little economic or environmental cost while providing water, through runoff, for regional agriculture and municipalities during the late spring to early summer. Storing water at high elevations and associated cooler temperatures is more efficient in terms of reduced evaporation rates. Likewise, water stored higher in a system is more conducive to water transfers and exchanges, because there is greater flexibility of where the water can be routed using gravity. Under a climate shift to earlier snowmelt runoff, not only would there be a greater demand for water to irrigate during the extended growing season, but water would be released from its very efficient high-elevation natural seasonal reservoir well before the July and August interval of peak irrigation. Infrastructural adaptations to enhance reservoir storage at lower elevations, though economically and environmentally plausible, would be less efficient due to likely higher evaporation rates.

CHANGES IN THE DEMAND FOR IRRIGATION WATER UNDER A CHANGED CLIMATE

A consumptive use model using a monthly estimation method was used to compute consumptive use and irrigation water requirements in the future under a changed climate.The monthly estimation method that was used is the SCS-Blaney Criddle method (USDA 1970) expressed as follows:

> *U = kt*kc*(t*p/100) where U = monthly consumptive use (in); kc = crop coefficient reflecting the growth stage of the crop; kt = climatic coefficient related to mean temperature; t = mean monthly temperature (degree F); and p = monthly percentage of daylight hours.*





The model allows for water supply information to be accounted for. In this case it was assumed that water supply is at all times adequate. The model was used to compute consumptive use (CU) and irrigation water requirements (IWR) for three different crops using climate data generated by several climate scenarios. The results indicate that under the Canadian Climate Centre model scenario experiment, perennial crops, grass, and alfalfa pasture may experience a 50 to 60% increase in the consumptive demand toward the end of the next century (top panel of figure). The application of the Hadley Climate Center scenario resulted in slightly less of an impact on the consumptive demand, 50% for grass pasture and approximately 30% for alfalfa (bottom panel of figure). Interestingly, the irrigated corn did not show any strong increase in consumptive demand. This result is most likely due to the slight increase in growing season precipitation, especially in the Hadley Climate Center scenario.

CHAPTER 5:

CROPPING SYSTEMS REPORT

Cropping Systems Report

Introduction

Risk reduction is the one critical issue that emerged from the cropping systems break-out group. This includes reducing the risk to the operator and his/her operation, and reducing risk to the community, both the local community and the larger US society. Because the rest of the country depends on Great Plains farmers to a large extent for their food, risk in the Great Plains may transfer to risk in other parts of the country if food production falters. Farming in the Great Plains has always been risky, but in recent months the economic risk has been heightened to new levels because of very low grain prices and increased fuel costs for most operators. Producers are going out of business at a faster rate now than at any other time in the past 10 years. Furthermore, extreme weather events, such as the 1996-1997 blizzards in North Dakota, followed by the 1997 floods in this same area, and the record heat wave in Texas in 1998, also put farmers at risk. If these extreme events increase in the future, farmers' ability to cope financially will be severely limited due to crop failures. So, risk reduction was the number one critical issue or concern among the farmers in the cropping systems group.

Currently in the region a number of cropping options are available and are being used by farmers based on the variability of climate, experience of the operator, and the market conditions. The range of dryland cropping options are presented in Table 5-1. There are five examples presented in the table ranging from the wheat-fallow rotation used in situations where severe water conservation methods are required, to crop rotations which have a crop in place for a greater proportion of the time. Finally, continuous cropping is possible under option four. Option five represents a case where the cropland is converted to grass, and a perennial grass is used. The other columns in the table describe the manner in which limits, soil and social factors, technology, and weather factors influence the option used by farmers.

Table 5-1: Characteristics of dryland cropping systems in the Great Plains.

	Dryland Cropping System	Limits (Parameters)	Soil Factors	Social Factors	Equipment	Climate Change Concerns
Complexity of Rotations Increasing	(1) Wheat-Fallow (tillage) assumed)	* water storage-stability, genetics * temperature in reproductive period * May-June precipitation * variability	* water storage capacity (decreasing importance as you go towards # 5) * increasing possibility of carbon sequestration as you go towards # 5 * pest concerns	* more demanding, more complex management skills (increasing as you go towards # 4) * # 1-3, to 4 – cash-grain mentality * # 4 to 5 – cash-grain to livestock mentality	* more resources needed for equipment as you go towards # 4	* If the climate change brings more erratic rainfall, it may push people towards # 5
	(2) Wheat-?-Fallow (? represents various crops that can be used in rotations)	* stored water buffer (non-crop period following wheat) * July-Aug precipitation for ? * temperature in reproductive period * no-till critical in non-crop period following wheat				
	(3) Wheat-?-?-?-Fallow	* warm season precipitation and temperature in reproductive period (if ? is a warm season crop) * lack of transition crops back to winter wheat * dual-function crops (forage/grain)				
	(4) Continuous					
Continuous Cover	(5) Perennial Grasses (permanent and rotated)					* If the climate change brings less erratic rainfall, will people shift out of livestock to more grain crops?

Once risk was established as the main concern for farmers, strategies to reduce risk, taking into consideration climate change, were discussed. Coping strategies suggested take many forms, but all are meant to reduce the risk which farmers have to deal with in their daily lives, whether or not there is a discernable climate change.

Coping Strategies

The coping strategies suggested here are strategies that can be used now in the face of extreme weather events. Already farmers are faced with droughts, floods, pests, and diseases which put their operations at risk. Droughts and floods are weather factors, and farmers have little, or no, control over these factors. Their only option is to build in risk management factors that minimize the environmental and economic effects of extreme events on their cropping operations. The sensitivity of existing crop varieties to climatic factors is already known (Table 5-2). Therefore, knowing the climatic ranges of certain existing crop varieties, adjustment of cropping systems to deal with changed conditions may be possible. The key concerns are how rapidly operators will need to be able to adjust cropping types to changes in weather; if there will be enough capital to accommodate these alternative systems; and if the operators will receive the weather projections in a timely and location-specific fashion.

It is likely that a change in temperature and precipitation will lead to a change in the crop mix grown in the central Great Plains today. It is useful to evaluate the central region of the Great Plains in relation to the northern and southern regions, because if the climate shifts occur and the conditions become like those in the northern or southern Plains currently, there are two models of systems in place there now which could be transferred to the central region. Table 5-2 shows a list of key crops in the central Great Plains region now, and the critical thresholds to grow these crops successfully. If conditions change, other crops can be substituted to maintain productivity. Likewise, Table 5-3 is a similar table for warm and cool season forage crops. It is unclear what factors will influence the decision of which forage a producer will pick to grow as conditions change. Temperature and precipitation (timing and form) are important. Projected seasonal patterns (winter, spring, summer) of temperature and precipitation need to be looked at explicitly to make informed decisions about the crop/forage types chosen.

Table 5-2: Grain crops grown in the Great Plains and critical temperature (°F) and water thresholds.

Grain Crops – Warm	Critical Periods – Temperature	Critical Periods – Water
Corn √	July-August (> 95°)	July-August ***
Grain sorghum √	August (< 50°)	August **
Sunflower √	July-August (?)	July-August **
Soybeans	July-August (?)	July-August ***
Proso millet √	----------------	June-July *
Dry beans	July-August (> 90°)	July-August **
Safflower	----------------	water at planting *

Grain Crops – Cool	Critical Periods – Temperature	Critical Periods – Water
Winter wheat √	June (> 85°) wind	May-June **
Spring wheat	June-July (> 85°)	June-July **
Barley	June-July	June-July *
Oats	June-July	June-July *
Winter canola	winter kill	June **
Spring canola	June-July (> 85°)	June **
Spring peas (pulse crop)	June (> 85°)	May-June ***

√ = key crops in the central Great Plains region presently * = least critical ** = more critical *** = most critical

Table 5-3: Forage crops grown in the Great Plains.

Forage – Cool Annuals	Forage – Warm Annuals	Forage – Perennials
Winter triticale Austrian winter pea Oats Oat-pea Canola Winter wheat Vetch Medic Turnips	Soybeans Hay millet Forage sorghums Pearl millet Corn (dual-purpose) Kenaf	Alfalfa Sweet clover Grasses (cool and warm) Legume-grass mix (alfalfa, medic)

Specific Coping Strategies Suggested

1) Using crop rotations

More intense and more diverse crop rotations can build organic matter (with many related benefits, including increasing soil water-holding capacity and preserving water quality) and minimize the occurrence of economic losses due to pests and diseases, which translates into less economic losses for farmers. Varying the types of crops planted will put diseases and pests at a disadvantage as they will not get a good hold on any one crop, therefore, minimizing their negative impacts to the farmer.

2) Supporting reformed crop insurance

Under the present crop insurance plan, multi-year extreme events limit the amount of insurance coverage farmers have available, while the premium remains the same. Given the possibility for more extreme events, it is important to reconsider the current crop insurance program to provide farmers with an option for a higher degree of coverage. Farmers using crop diversity with lower crop investments pose a smaller risk for failure, and should be granted credits that reduce their insurance premium.

Following from the argument presented above, reformed crop insurance needs to include: federal dollars being appropriated for emergency aid to Native American producers on reservations; as well as, the cost-of-production provisions and new provisions for better handling of insurance during multiple-year extreme events. Because Congress is now willing to look at crop insurance for the first time in 25 years, a resolution was sent to Congress signed by members of the workshop, to show their support for revisions in the current crop insurance plan.

3) Encourage climate scientists and farmers to organize a joint workshop on seasonal weather predictions

Better weather predictions, presented in an easy-to-use manner, would be extremely beneficial to farmers in the central Great Plains, especially if climate change increases the variability of the climate/weather in the region. The cropping group would like to encourage the planning of a workshop with users of climate information, in order to determine how best to disseminate seasonal/monthly climate information. The disseminated information needs to be useful, timely, user-friendly, reliable climate information - both seasonal and interannual. In this joint effort, farmers can inform the climate center personnel on what information would be beneficial to them, how that information should be presented, and where they would like to find it. Also, mailings and field days from extension personnel can publicize where to find this kind of climate information. It was generally agreed by the group that once the word gets out that the information is there, and that it's reliable, the dissemination will happen relatively easily, by farmers spreading the word among themselves. Long-term forecasts allow producers to make appropriate long-term plans necessary to maintain soil fertility and conserve natural resources. Reliable, short-term (growing season) forecasts enable a farmer to make more economically sustainable decisions regarding the mix of crops for the year.

There should also be more emphasis on research on El-Niño Southern Oscillation (ENSO) predictions (3-5 years). Because the worldwide weather patterns associated with El-Niño and La Niña are well documented, accurate ENSO predictions will allow farmers in the Great Plains to expect a dry pattern of weather when the La-Niña conditions are expressing themselves (see Chapter 1 – El-Niño Box). Therefore, if farmers receive accurate forecasts, they will know whether to expect a normal or a dry year, and they can plan accordingly. These predictions need to be disseminated to the wider community, and they need to be reliable, and available in a way that is easy to obtain, understand, and use. These predictions, which could be beneficial to the cause of disseminating seasonal to interannual climate predictions, need to have an acceptable level of confidence associated with them. Climate scientists had great success predicting the 1997-98 El-Niño event, therefore, in the future the general public may have more faith in predictions and use the information to their advantage.

4) Pursue legislation that encourages carbon sequestration

The cropping group would like to encourage research to determine the value of improving soil carbon, and promote legislation to encourage the adoption of financial incentives for carbon sequestration. As was discussed previously, carbon sequestration has many benefits to individual farmers, and to the larger society. Increasing the amount of carbon that is stored in the soil leads to increased water capture efficiency in the soil, therefore, precipitation received can be better managed. This will reduce the risk of droughts to farmers, by increasing soil moisture. Carbon sequestration can be accomplished through reduced tillage and crop rotations.

Furthermore, Natural Resources Conservation Service (NRCS) should be encouraged to educate producers about the benefits of carbon sequestration. This coping strategy also includes the need for more research to establish the value of carbon, and how an incentive program can be initiated. There are things that can be done now to sequester more carbon, and existing programs and agencies should find ways to make financial incentives for farmers who adopt these proven methods. A positive financial incentive for farmers to store carbon can also help balance out some of the other financial pressures farmers are encountering right now, and therefore, help preserve farming operations.

5) Encourage diversity

Diversifying operations can be a way that farmers can cope with possible climate change. Diversification can take many forms: spatial and temporal diversification, diversification of crop type, market, and income, as well as integration with livestock. Specific crops can grow under known weather patterns (Table 5-2, 5-3) and selection of these in appropriate combinations can be useful to reduce vulnerability to climate change.

Diversity in the crop mix: A variety of crops planted results in a variety of different growing seasons, changes in susceptibility to disease and insects, and less weather risk exposure (Table 5-1). As climatic shifts take place, the crop mix can be changed to take advantage of the altered climate (Table 5-2). Crop diversity can minimize the risk of a total farm failure.

Diversity in markets: Commodities, as well as specialty (high value) markets, should be looked at. In order to lessen transportation and processing expenses, and to enhance local economic conditions, local markets should be explored. These markets are also less risky than markets that are further away, because local markets cater to needs which are easier to identify and monitor, and not subject to the external politics and economic well-being of foreign nations. Communities should utilize localized production as much as possible before importing products. Community stability will be enhanced through expanding local markets, and local processing and distribution of products. This will build infrastructure, self-sustainability, and community well-being, thereby lessening the effects of regional and international conditions.

Diversified income can include both on-farm and off-farm activities. On-farm sources include diversifying the agricultural income, and bringing in non-agricultural income (hunting leases, recreation, etc.). This lessens the risk of financial failure due to specific crop failures, and also reduces the reliance on the agricultural markets. Off-farm income, such as a job in town, can also be a mechanism to reduce economic risk, if feasible.

Livestock diversification can be a technique to better use the available forage (grain, grass, shrubs, and crop failures). Livestock can be matched to available forage in order to give producers another income source.

Diversification research: A program that promotes diversity and includes research on what supports, training, or knowledge farmers may need to diversify would be beneficial. Communication with farmers may be a research project in itself. Consideration should also be given to the possible drawbacks to diversification, including lack of appropriate knowledge to diversify and the strain it may place on time resources.

6) Create decision-making tools to aid farmers who are deciding whether or not to integrate livestock into their operation

Many farmers may be thinking about the advantages/disadvantages of integrating livestock into their farming operations, but many may need help weighing the pros and cons. Diversification, including adding livestock to a farm, may help the farmer be less vulnerable to the effects of adverse weather and variable markets, by diversifying the products that can be sold. Some farmers may need help deciding whether or not it is beneficial for them to integrate livestock, so educational programs that create decision-aid tools can help them. Many farmers don't have the infrastructure to keep cattle, so this needs to be considered along with other factors related to the particular operation. Another related tool that can help farmers make wise decisions is a tool to help farmers establish their cost-of-production per acre. If farmers can establish this for their own place, they can better plan for and withstand adverse weather when it comes. Some tools to help them estimate their cost-of-production per acre are available now, but they are not widely used.

7) Increase USDA services on tribal reservations

Currently, reservations are chronically understaffed for the delivery of USDA, NRCS, and FSA programs. For instance, currently in South Dakota there is only one Tribal Liaison to represent all tribal members and lands for USDA programs. Reservations should have full offices similar to county offices to implement these programs.

Research Needs

Stemming from many of these coping strategies, are specific research needs that must be studied in order to adapt to the future climate.

1) Diversification

Research is needed on the best methods (or feasible methods) of diversification under certain climatic conditions and in specific localities. Many practices that may work very well in certain parts of the Plains, may not work in other parts. Soil types, rainfall, and growing seasons may limit what crops are possible in certain areas. For example, including leguminous crops, like field peas, lentils, and Austrian winter peas, in rotations has been successful in the Northern Plains, but of limited value in the Central Plains. Farmers must work with those crops that fit their region and local climate. Therefore, as conditions change location-specific studies need to be undertaken in order to match crops and practices with locations.

2) Valuation for carbon sequestration and other conservation credits

Before credits can be granted to farmers who store carbon, much research needs to be done on the value of this stored carbon. This is an extremely complicated subject, and it may well take many years to formulate a plan that is fair and equitable. This process should begin as soon as is feasible if this program is to be implemented anytime in the near future. Likewise, programs that encourage the implementation of other conservation measures, such as erosion control or provision of wildlife habitat, need to be further researched as alternatives for farmers that could provide positive incentives for conservation behavior.

3) New crop/variety development

Research by ARS and land grant universities to develop new crops/varieties for the Great Plains that will do well under a changed future climate also needs to be started today (see Table 5-1, 5-2). This research needs to be done with public and private resources, as many private companies may focus their work on seed development for current conditions and markets. The new seeds need to be bred for more than increased production; they need to also be bred for climate hardiness. Characterization of existing seed varieties for specific weather conditions should be catalogued. This would allow rapid transfer of new varieties into regions where growth conditions change. Waiting until the seeds are actually marketable will mean that there will be crop failure in the first few years of a changed climate until new, better adapted, seeds are produced, tested, and marketed. If seeds evolve as the climate changes or if there are available seed sources from known regions with similar climate to the 'new' climate, this will benefit farmers. Additionally, new research should be done on pesticides and herbicides that may be useful if certain types of pests/diseases increase with climate changes. With new crops come new pests, and these need to be taken into consideration when new seed is developed.

4) Hail research

Hail, also know as "the Great White Combine," is no stranger to the Great Plains. With climate change, may come increased hail events, or the timing on when to expect hail events may change. Therefore, further research on hail would be beneficial in coping with climate change. Research should look at the seasonality of hail, and the timing and number of occurrences. This may have implications for the type of crops that are grown in certain locations. Research does not have to be on suppression, but on the accuracy of predictions. Related to this, the linkages between the regional weather in the Great Plains and the ENSO signal needs to be studied more. Or, the research that has been done already in this area may need to be compiled and disseminated. Severe weather reports that include hail reports would be beneficial for more informed decision-making.

5) Possible water storage locations

If spring thaw in the mountains starts earlier in the year in the future, farmers may need ways and places to store that water until it is needed in the fields for irrigation. Although it is too early to start building infrastructure to hold water, the possibility that this needs to be done must be explored, and places and techniques to hold this water need to be researched.

Cross-Cutting Issues

1) Carbon sequestration

Carbon sequestering issues cut across all sectors studied in this central Great Plains assessment. Carbon storage will improve the water quality by retaining soil nutrients within the root zone, which will keep the nutrients out of the groundwater. Surface water quality will also be enhanced because of less nutrient leaching and soil erosion into the streams. Range management to raise soil carbon levels can also improve wildlife habitat. A well-managed grazing system will create wildlife habitat, slow runoff, and sequester carbon more than an ungrazed or overgrazed range.

2) Water competition

The issue of competition for water among various users was also brought up as a cross-cutting issue. Agriculture is still the main consumptive user of water in the Great Plains, but increasingly urban populations are expanding, and more water is needed for municipal use. Therefore, the future will see continued competition for water. A warmer, drier climate may exacerbate this competition. This cropping group would like to see cities looking to water conservation, efficiency, and reuse before looking to buy agricultural water and building expensive infrastructure to get/keep the water.

3) Endangered species and crop/range systems

A last cross-cutting issue is how endangered species regulations interrelate with farming, ranching, and conservation issues. The Endangered Species Act (ESA) has often been misused, and has hurt many farmers, so different sectors coming together to discuss this issue would be beneficial to all involved. Furthermore, there is concern that the ESA may prevent actions being taken in order to adapt to climate change (such as changes in cropping systems).

BENEFITS OF INCREASING SOIL ORGANIC MATTER

Soil organic matter can improve many soil properties, leading to looser and more porous soil, higher water-holding capacity, lower erosion potential, and greater soil fertility. Because of organic matter's ability to capture and hold moisture, increasing organic levels in soil is a key strategy in minimizing the effects of drought. Higher soil organic matter content (higher carbon levels), tends to lead to aggregate soil (many fine soil particles held in a mass or cluster) which improves penetration of precipitation, thereby minimizing runoff from small rainfall events (see figure). Soil management practices that preserve crop residues on the soil surface decrease evaporative water loss from soils and promote organic matter increases, although under very light rainfall events residues prevent moisture from entering the soil. Residues also protect the soil against the erosive forces of wind and water. Therefore, the net overall effect is more available water for plants and a better chance of making it through low or sporadic rainfall periods. In the event of increased temperatures, an increase in soil moisture evaporation can be anticipated which, in turn, increases the need for increased soil moisture holding capacity. The soil's ability to hold moisture also leads to less nutrients leaching into the groundwater. A higher organic matter soil has the ability to capture moisture which means less runoff to streams during small rainfall events. With high rainfall events, runoff still occurs, even with the best management practices. The water being captured with the new management practices that increase soil organic matter is mainly from the small rainfall events. Thus, the fact that more water is being stored in the soil from small rainfall events will not have a large negative impact on the water that goes into streams or recharges groundwater.

Warmer temperatures may decrease soil organic matter because it will increase decomposition of organic matter. Therefore, building soil organic matter will be especially important in the potentially warmer future climate.

Water holding capacity of soils with different levels of organic matter.

100 Pounds of Dry Soil With...

4% to 5% organic matter can
hold 165-195 lbs. of water
equal to 4"-6" of rain.

1.5% to 2% organic matter can
hold only 35-45 lbs. of water
equal to 1/2" - 1-1/2" of rain.

Below 2.5% organic matter, nitrogen, potassium, phosphorus, and other plant nutrients leach away (adapted from Walters and Fenzau 1979).

CHAPTER 6:

RANCHING AND LIVESTOCK REPORT

Ranching and Livestock Report

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Critical Effects, Coping Strategies, and Tactics under Climate Change

Effects of Climate Change on Quantity/ Quality of Vegetation

Climate change is likely to affect both the quantity and quality of rangeland vegetation. The structure and function of grasslands are largely a function of water and temperature. For instance, Great Plains grasslands transition from short-grass steppe to mixed prairie and finally tallgrass prairie as one travels west to east from the Rocky Mountains to the eastward extension of the Great Plains. This transition corresponds to a precipitation gradient from areas of low rainfall on the east side of the Rockies to areas of relatively high and more evenly-distributed rainfall in the tallgrass prairie region. At the same time, the temperature gradient from northern to southern Great Plains regions represents another important gradient that determines plant type distribution and local abundances (e.g., warm-season vs. cool-season grasses).

Climate change, caused by increased CO_2, will likely result in altered temperature and precipitation. The three environmental parameters of CO_2, temperature, and precipitation will in turn affect Great Plains grasslands, primarily through their effects on plant and soil water relations, photosynthesis, and other aspects of plant metabolism. Secondary responses that are likely to affect the long-term responses of grassland ecosystems to climate change will involve effects on soil carbon and nitrogen cycling. Responses will result from direct effects of the changing environment on individual plants (e.g., productivity), as well as from changes in plant communities which occur due to different sensitivities of individual species to climate change. One example of a CO_2 effect that may already have contributed to altered plant community structure is the conversion of southwest rangelands from systems dominated by warm-season grasses to a shrub-dominated system. The positive response of the shrubs to CO_2 enrichment may have played an important role in this phenomenon (Polley 1992). Likewise, an increase in the minimum temperature in the spring has been correlated with a decrease in the net primary productivity of Bouteloua gracilis (C_4 grass) in the short-grass steppe, and with increases in exotic and native C_3 forbs (Alward et al. 1999), contributing to the shift. Elevated CO_2 may also favor other invasive species, like undesirable annual grasses and forbs over current dominant perennial vegetation (Polley 1992). Though other factors, such as grazing management and fire suppression, have also contributed to increased woody encroachment of grasslands (Archer 1994).

Some changes, like enhanced forage production in response to elevated CO_2, may be beneficial. However, this direct effect on forage production may be overshadowed by changes in the balance of current dominant warm- and cool-season grasses, increased composition of legumes, or increased shrubs. Other factors related to climate change may also have a bearing on forage quality. Changes in forage quality from climate change may be either positive or negative in terms of nutritive value for domestic livestock, and negative changes may be overcome to some extent by greater intake of forage.

Fire in the Great Plains has been largely suppressed since the area has been cropped. Under climate change conditions, the frequency and severity of weather conducive to fire could increase. Likewise, changes in plant communities caused by climatic changes could alter their physical and chemical properties related to burning (Ryan 1991). Therefore, fire potential in the region will be impacted by climate change. In the last twelve years there has been a fourfold increase in the incidence of historically significant fires, compared with the twelve previous years (National Interagency Fire Center 2001). This represents an increase in fire activity, and the fact that humans are increasingly moving into areas where wildfires are more likely to burn (e.g. the foothills of the Rocky Mountains).

Large areas of the land in the Great Plains have been converted from native prairie to cropland and other land uses. Livestock enterprises are often a mix of range management, planted forage, and crop activities. Rangelands may be more resilient than croplands to climate changes, since the internal structure of soil and plant communities is maintained, whereas with traditional management of croplands, intensive inputs are required to maintain soil productivity, minimize soil erosion, and replace vegetation annually. However, there are still some livestock operating systems that may not be very resilient.

In regards to possible producer responses to climate change, the group stressed the importance of having incentives in place that would promote sustainable management systems, including practices that lead to increased soil organic matter, carbon sequestering, and efficient use of water. To deal with these changes in climate and climate variability, the following specific coping strategies will be important.

1) Land Conversion/Change in Enterprise

A good example of land conversion or a change in enterprise could involve water, because it is viewed as the major determinant of agricultural practice in the Great Plains. If climate changes are significant enough to alter the agricultural potential of a region due to changes in growing season water availability, then there will be pressure to convert land in the direction dictated by that change (e.g., rangeland to cropland, rangeland to improved pastures, or vice versa). A shift in enterprise is another possible response to climate change. Changes in enterprise could include: using new livestock breeds developed for specific conditions (e.g., more heat-adapted species); increased or decreased reliance on improved pastures for supplemental grazing; and/or improved or better-adapted forages for supplemental grazing or for enhanced pest and disease resistance. Some alterations in vegetation management associated with climate might be necessary for subtle reasons. For example, the recent summer of increased humidity experienced in the eastern Great Plains delayed haying operations as the plants were often too wet early in the day to harvest.

2) New/Improved Grazing Systems

On rangelands in which management is relatively extensive and input costs minimal, changes in management strategies for domestic livestock has been and remains one of the major coping mechanisms to deal with the climate variability of the Great Plains. Various rotational, prescriptive, and season-long grazing strategies are available and need to be evaluated in terms of their performance under climate change, including their sustainability, economics, and capability to store carbon. These strategies involve:

- number of animals
- species/class of animals
- rest/rotation grazing systems
- distribution/concentration of animals
- complementary pastures
- improved pasture development

3) Efforts to Understand Pest/Disease Vectors

Climate change may involve environmental perturbations (drought, flood, temperature changes) that are likely to affect life cycles of various pest/disease organisms, and could exacerbate problems due to outbreaks. For instance, grasshoppers are sensitive to wet/dry periods, although this sensitivity is quite variable among species of grasshopper. Possibilities of increased rust (a disease caused by a rust fungus) on native grasses under higher humidity patterns, such as was experienced in the eastern Great Plains in a recent summer, may increase if ambient humidity increases. Our present ability to predict the relationship between these pest outbreaks and climatic conditions is limited and patterns of outbreaks may change in future environments in ways that are not predictable from our present knowledge. Efforts are needed to understand how climate change will impact such outbreaks, and what managers can do to plan for, combat, or otherwise deal with them.

4) Efforts Need to be Made with Land Managers to Recognize Function and Health of the Ecological Processes

The effective functioning of the water, various nutrient and energy cycles, as well as plant community succession, can buffer both long and short-term impacts and cycles of weather and climate fluctuations. For example, if a grassland community is allowed by management to be diverse with abundant vegetative cover that supports an extensive fibrous root network, then soil permeability is increased, compaction is decreased, and the soil surface is protected from erosion. The reciprocal would be a community of low diversity, surface compaction, and bare surface soil that would result in unstable watershed hydrographs, soil erosion, and water quality degradation. Invasive species and brush encroachment into rangelands may also be a problem under climate change. Likewise, as discussed earlier, fire regimes and potential will be altered under a changed climate. This will have impacts on ecosystem function and health. In short, the recognition of the function and health of rangelands and the management of lands toward healthy, effective ecological function is essential in the buffering against long-term climate changes.

Effects of Climate Change on Domestic Livestock

Climate change will likely affect domestic animals both indirectly and directly. For example, alterations in forage production may have indirect effects on animals. The most obvious direct effect will be caused by temperatures, since both hot and cold temperatures already impose important limitations on livestock operations. If humidity increases, this could exacerbate the problem of high temperatures for livestock. If significant changes in precipitation patterns develop, then those too will likely impact livestock.

Specifically, Hahn and Morgan (1999) report that potential climate change impacts will reduce summer season production, reproduction, and efficiency of domestic animals. Increased incidences of extreme events, such as heat waves, are also expected to not only reduce performance, but may also result in death of more vulnerable animals. Following are some potentially useful coping strategies for those working with domestic livestock.

1) Mix or Change Animal Species and/or Breeds to Suit New Environmental Conditions

Cattle, bison, sheep, goats, etc. have different adaptabilities to the environment, as do breeds within species. These differences should be considered in regard to the changing environment, to help match grazing species with the plant communities that result from change. This also applies to the possibility of including more than one species in a grazing operation.

2) Change Timing of Events

The timing of important events in the raising of livestock, such as calving, lambing, and weaning, could be modified in response to a changing climate.

3) Lessen Stresses

Where climate change results in additional stresses, production practices will need to shift away from stressful environments (e.g., intensive operations) or practices will need to be modified in stressed environments (e.g., lower livestock numbers on water-stressed rangelands; reduce environmental heat loads by using shades, sprinklers, or other means during the summer).

4) Monitor Pests/Diseases

As with plants, climate change will likely perturb pests/diseases of domestic livestock (e.g., hornflies, brucellosis), and management practices will need to be developed to counter any resulting problems (Rosenzweig and Hillel 1995).

Effects of Climate Change on Wildlife Populations

Projected climate changes will likely impact all species of wildlife, including insects, birds, fish, amphibians, reptiles, and large and small mammals. In addition, it is known that agricultural practices also have important effects on wildlife populations. Coping strategies that may prove beneficial in assisting wildlife populations to adapt to climate changes could include integrated management strategies specifically for wildlife. This involves determining and adopting management strategies and systems that are directed towards maintaining appropriate levels of quality wildlife (levels that do not interfere with the operation of a livestock operation). This is a cross-cutting issue that will involve management of domestic animals, crops, water and land use practices, and will require community-wide collaborations to maintain or restore appropriate wildlife habitats in addition to the more usual producer concerns. Issues to be addressed include habitat fragmentation and wildlife corridors, changing hydrological regimes, rural and urban development, and the use of chemicals and other new technologies that may impact wildlife or their habitat. An important matter will be how to achieve this in a manner that engenders support from all concerned.

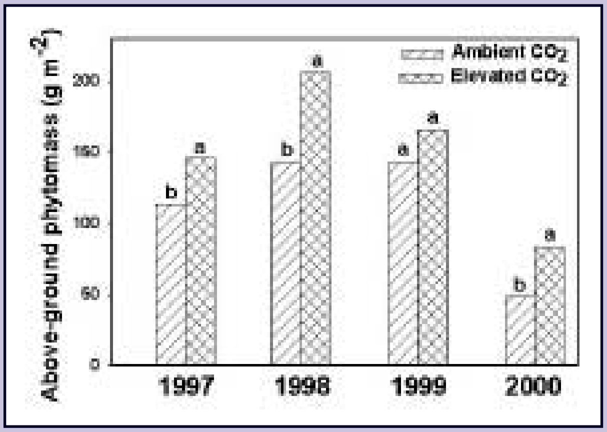
The rangeland and livestock group also discussed some future climatic and economic/policy scenarios, and coping strategies to deal with those expected impacts. The discussion of those scenarios is included in Appendix E.

PHYSIOLOGICAL RESPONSES OF GRASSES TO INCREASED ATMOSPHERIC CARBON DIOXIDE

Research conducted in large open-top CO_2 enrichment chambers on shortgrass steppe vegetation in north-eastern Colorado has provided scientists from USDA-ARS and Colorado State University with insights into how elevated CO_2 will affect productivity and ecology of these grasslands (left panel of figure). The site contains a mixture of mostly warm- and cool-season grasses, and is representative of much of the vegetation found in the Great Plains. The CO_2 level in three of the chambers is maintained at 720 parts per million, twice the concentration in the other three chambers which are maintained at the present ambient level of 360 parts per million CO_2. Current models project that atmospheric CO_2 concentrations will increase above 720 parts per million before the end of the 21st century, under a "business-as-usual" scenario.

Aboveground productivity of native grasses and forbs has been consistently enhanced in the chambers under double ambient CO_2, as indicated by increases in aboveground peak phytomass ranging from 20% to 71% (right panel of figure). The greatest relative increase (71%) occurred in a dry year (2000) in which production at peak standing crop was about half of the long-term average for the site. However, protein concentrations tend to be lower under elevated CO_2, so while forage production may go up in future CO_2-enriched environments, forage quality may decline. After four years of CO_2 enrichment, no relative differences in growth responses to CO_2 have yet been detected between warm- or cool-season grasses. These results on the CO_2 effect alone need to be evaluated in regard to the changing climate, but suggest important changes in the ecosystem that will affect management strategies. One particular issue will be the possible need for supplemental nitrogen to maintain forage quality in future CO_2-enriched environments.

Open-top CO_2 enrichment chambers on the short-grass steppe in north-eastern Colorado.



Above-ground productivity increased with elevated CO_2 as measured by above-ground phytomass.

EXTREME EVENTS

Climate change could bring about changes in both the frequency and severity of extreme events (droughts, floods, heat waves, winter storms) that could impact agriculture, grazinglands, intensive livestock operations, natural systems, hydrologic systems, and human communities. Although the ranching and agricultural economies have proven resilient to historic extreme events, the toll on individual producers has been heavy and remains memorable. The key issue is the possibility that these extreme events, like drought, would occur in greater frequency and/or for longer durations, so that instead of a one year drought there might be a 2 or 3 year drought more frequently. Producers agreed that three bad years could wipe out even a well-capitalized producer.

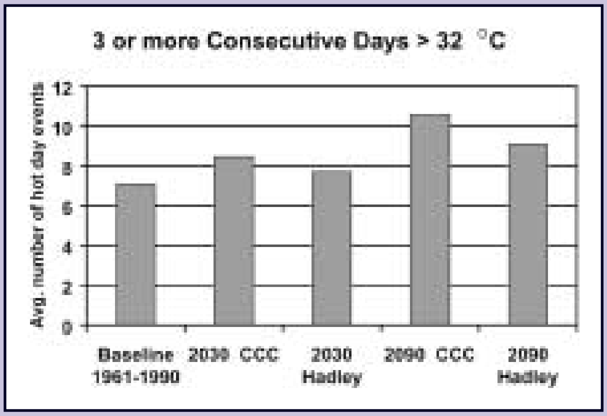
For natural systems, frequent extreme events could lead to extinctions if populations (flora and fauna) do not have sufficient time to recover from the perturbations. For hydrologic systems, the management of dams and water containment systems may need to be reconsidered given the possible changes to historic flood and drought periods. Coping strategies include appropriate crop and livestock insurance coverage to deal with droughts, floods, or other extreme events, and increased feed reserves including harvested forages and using grazing reserves as a buffer against extreme events for the livestock sector. For example, the possibility of grazing Conservation Reserve Program (CRP) areas and commons areas that are grazed only during periods of low forage supply should be explored. Enterprise diversification could also be a way to cope with extreme events, as diversified systems are generally better able to withstand extremes. Improved weather forecasting could also assist producers in real-time management decisions. Water reserves may also need to be increased if future climate is characterized by more severe summer droughts. Likewise, for human systems better preparedness to react to extreme events quickly and efficiently will be important for successful coping.

Dust Storm

Drought

INCREASED HEAT WAVE IMPACTS ON LIVESTOCK WITH GLOBAL WARMING

Current climate change scenarios (e.g., CCC and Hadley GCMs) project global warming, with consequent increased frequency and severity of heat waves (see figure) and other extreme events. The potential for more frequent and more severe heat waves, along with projected increases in minimum daily temperatures, are of particular concern for livestock producers whose animals are typically in unhoused settings. Animals usually maintained in housed production facilities (poultry and swine) also can be adversely affected, but such facilities can more readily incorporate measures to counteract the effects of extreme events. Even under current climates, heat waves can be costly for livestock producers. Moderate heat waves cause reduced growth rates and increased feed costs, while stronger heat waves, such as experienced in the central United States in 1992, 1995, 1997, and 1999, can also result in death losses. The heat waves of 1995 and 1999 were particularly severe for feedlot cattle in Nebraska and Iowa, where economic losses from death and reduced performance were estimated to be $28 million in 1995 and $40 million in 1999. Although strategic measures (e.g., shades or wetting by sprinklers) can reduce death and performance losses, they are expensive to install and maintain. Increased incidence of heat waves with global warming, as reflected in the figure, across broader geographic regions may require application of such environmental practices in many locations where they are not currently considered. Also, projected increases in daily minimum temperatures may worsen the impact of the heat waves, because of the decreased opportunity for nighttime recovery from the effects of daytime heat stress.



Incidence of Hot Day Events in the Great Plains (3 or more days exceeding 90°F [32°C])

CHAPTER 7:

CONSERVATION/NATURAL AREAS AND WILDLIFE REPORT

Conservation/Natural Areas and Wildlife Report

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System Level Responses/Impacts: Current Stressors

Natural systems in the Central Great Plains are currently stressed by a variety of agents. These stressors are likely to interact strongly with the effect(s) of climate change. To what extent climate change will ameliorate or exacerbate these impacts, however, has not been substantially validated for the Central Great Plains region. Current stressors to aquatic natural systems include: markedly altered hydrology resulting from ubiquitous impoundments and diversions of water that affect the flow of streams and rivers throughout the region; a change in overland sheet flow dynamics resulting in the isolation of surface water and the inhibition of water to be exchanged over large areas caused by the construction of new roads; changes to the natural runoff of water from watersheds due to human intervention that has altered the natural efficiency of watersheds and the permeability of soil surfaces; the degradation of water quality through increased levels of sedimentation, pollution from fertilizer and pesticide runoff, and elevated water temperatures; and, the removal of riparian vegetation.

Terrestrial natural systems are also experiencing widespread environmental stress. Many landscapes in the Central Great Plains region have been substantially altered by intensive agriculture, while others, particularly landscapes used for grazing, remain essentially intact. Fragmentation of native grasslands by roads and agriculture threatens the region's biological diversity. The invasion of exotic (non-native) species exacerbates this threat. Increasing human demands on natural systems for wildlife viewing and hunting and recreational opportunities are likely to continue to cause direct stress on natural systems. Indirectly, there will be elevated pressure to develop natural systems for human needs, such as food and fiber production, if warming and drying reduces agricultural output in other historically productive competing agricultural areas in the US and worldwide. Such reductions will likely accelerate conversion of natural systems in the Central Great Plains region to intensive agriculture. Conversely, favorable conditions in other productive agricultural areas may lead to the reestablishment of natural or conservation areas in the region.

Effects of Climate Change on Current Stressors

There was strong consensus that possible warming and changes in precipitation patterns are likely to interact strongly with the effects of the stressors described above. Natural systems are dynamic. The ability of natural systems to adapt to climate change will depend on the rate, not just the magnitude of the change. Climate-ecosystem interactions and the inherent uncertainty associated with a variable and changing climate pose a formidable threat to the region's biological diversity and to the functioning of aquatic and terrestrial ecosystems. Aquatic systems, in particular, are already being pushed to their limits, due to habitat destruction and warming water. Rising temperatures and increasing demands for water will stress aquatic systems beyond sustainable capacities. For example, many species could experience temperatures beyond their thermal tolerances (see Covich et al. 1997). The fragmentation of surface water by impoundments and diversions can substantially impede the ability of aquatic species to adapt to changing water temperature by inhibiting their migration to cooler waters. Warmer water temperatures will decrease oxygen retention, thereby increasing stress on many aquatic organisms. Simultaneously, an aquatic species oxygen demand will be elevated as metabolic rates increase in response to warmer water.

The invasion of exotic species into terrestrial systems is likely to accelerate in response to longer growing seasons, because they will have more time to establish themselves. This could amplify the harmful competitive effects of these species on native biota. Outbreaks of insects and pathogens could be amplified by warmer winters, because the cold temperatures associated with winter historically caused mortality sufficient to dampen these eruptions.

It was widely agreed in the group that understanding extreme events (i.e., droughts, heat waves, floods, etc.) is key to understanding the potential impact(s) of climate change on natural systems. Extreme events are likely to cause elevated mortality, and the persistence of natural systems, including animal populations, will depend on adequate time intervals for recovery. If such intervals are excessively brief (e.g. due to increased frequency of extreme events), then the likelihood of local extinctions will increase.

Understanding the rate of change in temperature and precipitation will likely be more important than understanding the long-term endpoint. Natural systems in the Great Plains have evolved with high levels of climatic variability and have many built-in mechanisms that allow them to be somewhat resilient to climate change. Such resiliency, however, depends on sufficient time for adaptation. If climate change occurs rapidly, natural systems may not be able to adapt at a rate that ensures their survival – leading to a loss in regional biodiversity and local extinctions.

Coping Strategies

Each community has different needs and values, therefore, a community-based, non-regulatory approach would best meet the needs of addressing issues related to adaptation and mitigation of climate change. Rather than identifying specific strategies, a set of general principles was developed to guide social responses to climate change.

The five fundamental principles follow. First, there is a high level of uncertainty in climate projections and even greater uncertainty associated with how natural systems will respond. Developing detailed coping strategies based on projections of future behavior of natural systems is not tenable. Instead, strategies should focus on 'no-regrets' actions that make sense given the current environment and management practices used, as well as address a broad range of future climate scenarios. These types of no-regrets strategies are particularly feasible for natural systems because current environmental stressors could begin to be addressed and mitigated through the implementation of beneficial strategies today, and have a positive influence on future stressors/impacts that may accrue from a changing climate.

Second, the key to developing effective coping strategies for present and future stresses is to provide organisms with alternatives for adaptation. For example, alternatives are provided through landscape heterogeneity and high levels of connectivity in aquatic and terrestrial systems. Landscape heterogeneity depends on maintaining appropriate disturbance activities, such as fires, floods, debris dams, or grazing. In many cases disturbance activities need to be created by management actions, such as cattle grazing, prescribed burning, and flood management, in order to compensate for the changed land context interfering with natural disturbance regimes (e.g., loss of buffalo herds, absence of wildfire). The idea of enhancing land stewardship by private landowners is central to the success of this management principle.

The third principle focuses on preserving current land-uses that promote integrity in natural systems. This would entail, to the extent possible, encouraging conservation and restoration of systems through proper land management. A fundamental need in implementing this principle is to identify actions that foster long-term economic vitality while at the same time enhancing ecosystem resiliency.

The fourth principle must be accomplished in the context of adaptive management. It is critically important to learn by doing. There needs to be constant evaluation of what works and what fails to work in an attempt to lessen the impact(s) of climate change on natural systems.

Finally, effective coping strategies depend on informing the public and decision makers about the implications of climate change for natural systems and what the effects of changes to natural systems mean to the quality of human life. For example, what is the role of wetlands in flood control and in the hydrologic cycle and why is this important to society? What could changes in the natural system mean to a community or to natural systems on a local and regional basis? This principle is an overarching concern that should be fundamental to the discussions of climate change in each region included in the National Assessment. It can also be an effective way to educate the general public and decision makers about the related issues involved in the climate change debate.

Research/Information Needs

Several research and informational needs were identified. The need for better data related to current conditions, status, and stresses of natural systems, and a better understanding of the interactions between climate change and natural systems is vital in order to support decisions on social responses to climate change. The following needs identified by the breakout group are substantially more topical in nature than the general principals outlined for coping strategies. Topics for further research and informational needs include the following:

1) Given the importance of extreme events and the possible rate of change described above, climate change modelers should increase their efforts to better inform stakeholders, decision makers, and the general public of what is presently known and the uncertainties related to these issues.
2) Research is needed to better understand ecological and physiological thresholds of organisms and their tolerances to changes in temperature, salinity, sedimentation, disturbances, etc.
3) There is a need to better understand the cumulative effects of multiple stressors on natural systems. For example, it will be important to understand the interaction of warmer temperatures that may degrade water quality and the related impacts on aquatic biota.
4) The consequences of the loss of biological diversity for ecosystem services to humans and organisms need to be better understood.

5) Given that many natural systems in the region are substantially altered by human action, there is a need for research on restoration techniques. For example, what techniques and approaches are effective to restore biological diversity and ecosystem services to degraded systems?

6) Consider and research alternative agricultural reserve programs to provide easement incentives to land owners in order to keep ecosystems intact and safe from further fragmentation and development, or provide corridors for the movement of wildlife.

7) The role of wetlands in sequestering carbon needs to be better understood to help quantify benefits to landowners and the government in determining the value of wetlands as a possible participant in a future carbon banking system.

8) A pressing research need is the synthesis of current knowledge relevant to climate impacts relating to natural systems. This synthesis can then be used to develop and drive appropriate ecosystem models and to identify research and policy needs.

INVASIVE SPECIES AND BIOLOGICAL RESOURCES

The condition of the plant communities in the Great Plains is important to the agricultural and ecological well-being of the region. Changes in the natural vegetation and other environmental factors are changing the biodiversity of the region and affecting pests and disease incidence. In natural ecosystems, invasive species may compromise the ecosystem's ability to maintain its structure or function. Invasive species exploit the susceptibility of different habitats to multiple stresses, and climate change can influence their dispersal. Changes in winter moisture and temperatures can be advantageous to cool season invasive species, increase the extent of sagebrush and other woody perennials on the range, and allow certain disease vectors to persist. Also, summer increases in temperature and precipitation may impact woody encroachment and fire management. This has important implications for natural resource management and human settlement patterns.

The following are economic impacts of invasive species. USDA estimates that the costs of weed-associated losses in crop and forage production in the agricultural sector are nearly $15 billion annually. Crop losses in Kansas are annually $40 million from field bindweed. With an ability to reduce wheat yield by 25%, jointed goatgrass has infested 5 million acres of winter wheat and is spreading at a rate of 50,000 acres or more a year. Leafy spurge has been reported in all of the Great Plains states except Oklahoma and Texas. The grazing capacity of areas with more than 10 to 20% leafy spurge cover is significantly reduced. USDA estimated that the direct and secondary economic impacts of leafy spurge infestations on grazing land and wild land in North and South Dakota, Montana, and Wyoming amounted to approximately $129 million.

Associated with climate change will be a number of indirect effects that will modify the ecological integrity and biodiversity of many of the ecosystems in the region. There may be an increased number of noxious weeds, greater pest outbreaks, increased rate of aquifer use, and loss of wetlands for waterfowl due to increased temperatures in the region.

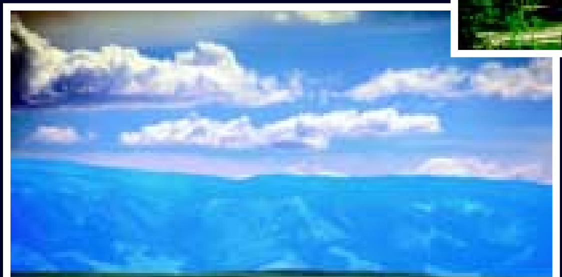
Field Bindweed

Jointed Goatgrass

Leafy Spurge

CHAPTER 8

CROSS-CUTTING ISSUES: SOCIAL ISSUES; CARBON SEQUESTRATION; WATER ALLOCATION; AND FORAGE, LIVESTOCK, CROPS, AND WILDLIFE INTERACTIONS



Cross-Cutting Issues: Social Issues; Carbon Sequestration; Water Allocation; and Forage, Livestock, Crops, and Wildlife Interactions

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Social Issues Related to Climate Change in the Great Plains

Social concerns related to climate change in the Great Plains stem from the vulnerability of inhabitants, and the implementation of coping strategies designed to adapt to or mitigate those vulnerabilities. Vulnerability can be defined as the state where systems and humans may be impacted negatively by changes. Adaptation involves reorganization in response to changes and challenges. The desired outcome of adaptation to climate change will involve increased resiliency in both the human and natural systems.

Infrastructure, including political and social structures, could also be vulnerable to climate change. Policies have the ability to impact human adaptation, depending on how they are developed and implemented. Information transfer, particularly related to climate change and coping strategies, is also tied to the adaptability of humans in the region.

Climate change will affect human well-being. Well-being can be measured in a number of ways, but the following are particularly important. Climate variability already has a huge impact on the household economy and it is likely that increased variability under climate change will have a greater effect. Quality of life and personal satisfaction are measures important to the sustainability of any community and include factors such as health care services, education, and other community services, and level of stress associated with economic well-being. There are a number of coping strategies inhabitants of the Great Plains can use under conditions of climate change to enhance their well-being. These include:

1) Diversification of Land Use to Increase Profits and/or Reduce Risk

Diversification can take many forms. It is often used to distribute risk throughout many facets of an operation. An example includes a strategy that some operators have already adopted, diversifying agricultural operations to include recreation and hunting venues. There are both advantages and disadvantages to diversification, however, that need to be explored before decisions are made regarding land use diversification.

2) Adoption of Public Policies

The public policies adopted in response to climate change should directly enhance quality of life for Great Plains inhabitants and indirectly enhance quality of life for the entire U.S. population. This is complex and entails many issues. Overall these policies/partnerships should be flexible, diverse, and available to operators, but not imposed on them. Policy that helps operators manage risk through affordable crop insurance is one example, and the selling of carbon credits is another example. Other possibilities include policies/partnerships which help develop community needs of the residents, such as appropriate health care, educational needs and other community services.

3) Develop Improved System-level Management Aids

Agriculture as an economic enterprise on the Great Plains has survived because of its ability to be flexible in the face of the harsh climate of the Great Plains and the recurring climate extremes. With the possibilities of climate change impacts, enterprise operators will need to think strategically, so that they will have the resources ready to respond tactically to climate change. Decision support systems (DSS), if implemented, would provide a synthesis of information for operators. The DSS might address potential economic outcomes of different strategies or tactics under different climate scenarios and also the economic effect of not doing anything.

4) Developing Local Markets for Diverse Products

Local markets can bolster a community's economy by providing outlets for diverse, local products. By keeping the market close to home, the community can increase their resiliency by expanding their local economy and reducing transportation costs.

Each of the break-out group reports include coping strategies to deal with the impacts discussed, and some of these include social issues related to impacts and coping.

Carbon Sequestration: Opportunities for Carbon Storage

The expansion of European settlers into the Great Plains resulted in a large-scale agricultural development as native prairie was plowed under, crops planted, and domestic livestock grazed on much of the remaining grasslands. One result of this development has been the depletion of soil organic matter, a consequence that has been recognized for some time. Today, considerable research in agriculture is directed towards developing sustainable practices that reverse the degrading effects of agriculture on soil organic matter. The more recent concern of enrichment of the atmosphere with greenhouse gases, most notably carbon dioxide (CO_2), presents an opportunity to combine our concern of soil conservation with the problem of greenhouse gas emissions. To do this, agricultural practices which result in the net uptake of carbon from the atmosphere with deposition into the soil, a process referred to as carbon sequestration, could be promoted. This will help counter the release of carbon into the atmosphere from the burning of fossil fuels, as well as assist in the restoration of soil organic matter in degraded systems, a long-time goal of soil conservation policy and practices. Further, the projected increased temperatures could lead to increased releases of CO_2 from soils in the region. Therefore, an additional reason for building the soil organic matter now will be to maintain organic matter at current levels under current land use practices into the future.

Research involving grazed and cropped agro-ecosystems, as well as natural areas, suggests there is potential for storing carbon in all of these systems. However, facilitating this will take a concerted effort, and will require the development of a strategic plan. For instance, sustainable agricultural practices like no-till or minimum tillage farming have been known for some time; however, there are considerable impediments to the adoption of these new practices. Changing an operation that historically has used conventional tillage cropping involves equipment and other operating expenses that prevent many producers from adopting the new technology. Another impediment is human nature. Some producers/land managers may be reluctant to adopt a new technology that they do not fully understand. Even with wide-ranging support for development of a system that supports managing agriculture and natural areas for the purpose of storing carbon, the logistics of how to determine and monitor practices for their capabilities to store carbon is not trivial. Finally, a plan to encourage carbon storage along with soil conservation requires a good system of technology exchange among all concerned. With this in mind, the group recommended the following plan for addressing policy on carbon sequestration and the use of carbon credits in agricultural programs.

Carbon Sequestering Plan

1) Any plan which supports carbon credits as financial incentives for promoting sustainable agricultural/land use practices that results in the net accumulation of carbon should be linked to existing and/or new policies supporting soil conservation systems. Soil conservation practices/systems already enjoy wide support, so linking carbon credits to soil conservation supports an already popular and effective program. The additional benefit is the potential for countering the emission of greenhouse gases and the negative effects those emissions could have on the world's climate.
2) A program directed towards sequestering carbon and promoting soil conservation will require national support. However, the particular issues of how best to accomplish this are in large part a local matter, since agricultural/natural systems and their operation/management are unique to the many climatic regions within the United States. Therefore, the group proposes that a national policy be developed in order to fund research and manage a carbon sequestration program for agriculture and natural systems. However, the group suggests that the implementation of this program be done at the local level by organizations like the Natural Resources Conservation Service (NRCS), which are already in place and well-poised to understand local production practices.
3) Education will be vital to the success of this program. Producers/managers/local program coordinators will need to understand carbon science in the particular systems they operate under, to effectively identify and implement appropriate management required to accomplish the objective of sequestering carbon. Perhaps more importantly, the American public will need to be educated to understand the importance of the Great Plains and the complex interactions between agricultural, land use, and environmental concerns and the objective of storing carbon in the landscape.
4) The attainment of viable management practices for storing carbon and conserving Great Plains land and aquatic areas is a complex issue, and will require new knowledge. The group proposes that research be supported which strives to understand the carbon cycle in the context of the ecology of Great Plains systems, and under a spectrum of management practices, with the objective of using that information to develop conservation systems that lead to carbon storage and soil conservation. The group also proposes that economic research be directed towards understanding how best to achieve the goal of promoting sustainable management practices, including carbon sequestration.

Water Allocation

The water allocation break-out session group centered around discussion of a concern voiced by the livestock group that if water becomes less available in the future, there will be a movement of its use out of agriculture and into urban uses. If that occurs, it could have adverse impacts on livestock production, particularly the finishing of animals with irrigated grain in intensive livestock operations (feedlots). An ultimate result for the livestock industry might be more grass-fed rather than grain-fed finished cattle. The group noted that while urban uses are likely to have the resources to outbid agricultural users for water, urban uses tend to be small and not highly consumptive. Therefore, it is likely that agricultural uses can continue downstream of urban centers, for example, by making use of treated effluent.

The group noted that water allocation in this region is highly decentralized, being based mainly on historical water rights rather than on the decisions of a centralized agency. However, where Federal agencies, such as the Bureau of Reclamation, are important, they play some role in the allocation of water through their water delivery contracts and their ability to build drought allocation rules into such contracts. Otherwise, water rights are property rights and allocation is determined by the ownership and seniority of those rights. The demand for security for urban uses can be accommodated through transfers of water or water rights from agricultural uses and various other sorts of contracts. These may include drought contingency contracts, whereby a senior agricultural user will take a payment in return for a promise to rent water to the city during low water periods; lease-back arrangements, whereby the city buys the right but leases it back to the farmer in all but critically dry years; and no-call agreements, whereby a downstream senior user agrees not to deny water for an upstream urban use. Such agreements are easier to negotiate and enforce in some settings than in others – for example, where the uses draw from the same surface stream. These negotiations may be more difficult where water uses depend on groundwater reserves.

The group also discussed interstate water allocation and the costly disputes that are ongoing in the region. It was noted that the outcomes of lawsuits are not likely to be very flexible or adaptive to a changing climate. The group concluded that water managers should give attention to developing legal, economic, and socio/political institutions which can be flexible. This may require some up-front investments, for example, in documenting and measuring current water uses to provide a better basis for negotiating and enforcing water allocation agreements. The group would like to encourage cooperative planning efforts and negotiated, rather than litigated, interstate allocation agreements along the lines of the current tri-state/federal process, between Wyoming, Colorado, Nebraska, and the federal government, aimed at creating a recovery plan for endangered species on the Platte River Basin without significantly interfering with existing and planned water uses.

The group also explored the concept of nested-governance that came out of the Western Water Policy Review Advisory Commission effort. Nested governance is an attempt to vest more power at the local level while enhancing coordination at the larger scale. The idea is to use local watershed councils for small scale water resource policy decisions, with progressively larger, more comprehensive bodies guiding policy at larger sub-basin and major basin scales. The value of improving the flow of information between areas and watersheds regarding what works was also explored. It was noted that a number of states have information delivery systems for agricultural/meteorological information, such as evapotranspiration (ET) estimates available in real time. These systems enable more efficient use of available water supplies.

Forage, Livestock, Crops, and Wildlife Interactions

There are six main points that came out of the forage, livestock, crops, and wildlife interactions group. First, there is a need to design non-threatening mechanisms for sharing information between agriculturalists and naturalists. Second, for biodiversity to be preserved, it needs to be marketed in some way; ecotourism may be an example. It will be important to market wildlife to show their value, not necessarily monetary value, but aesthetic and ecosystem stability values. This includes looking at more than game species, as well as a better understanding of complex relationships of plant, animal, and microbiological life. Third, there is a real need for people living in rural areas of the Great Plains to develop relationships with people outside of the Great Plains, and in urban areas in the Great Plains, in order to stress the important contributions of the region to the well-being of the nation as a whole. This may include a notion of the US Great Plains as a place where the ethics of self-reliance, and understanding the native and existing biological systems is paramount. Fourth, there needs to be more research to coordinate cropping/grazing systems with critical periods in wildlife reproduction (courtship, nesting, etc.). A chart of critical times can be established and agricultural practices can be somehow modified to benefit all systems. Fifth, there needs to be better education regarding the concepts of biodiversity, climate change, conservation, and ecology as part of our culture. It seems that in some cases children in America today know more about ecological issues in foreign countries than they do about issues right here at home. Furthermore, much education in schools regarding biodiversity may be anti-agricultural. This needs to be changed. A multi-use perspective needs to be used in the education system. And last, the resilience that comes from diversified operations including permanent grasslands and forbs, crops, and livestock should be expressed. This builds alliances within the community, because farmers and ranchers can work together to weather bad times, and these integrated systems can also benefit wildlife.

An example related to waterfowl and wetlands takes many of the above points into account. Waterfowl have international importance, and they have protein requirements that need to be met for survival. Some species are highly adaptable, such as ducks, and will move to find a location suitable for courting if their traditional location has been altered, but other species habitually return to the same place each year and do not move if their location is destroyed. Wetlands are especially important for waterfowl courtship. However, wetlands are apt to be especially important to someone looking for hay during a drought. Wetlands also have an enormous capacity to store carbon if fully wet, which may be especially important as climate changes. It was pointed out that even haying can be compatible with wildlife if it is done at the right time and with the right equipment.

All coping strategies should capture the dynamic nature of the climate system and of wildlife. There needs to be an awakened awareness of recognition for all biological organisms in management strategies, not just to include concern for game animals. The key is flexibility to manage a dynamic system. Once again, variability, or extremes, is more important to look at than average trends in climate conditions.

One coping strategy related to this issue of multiple-use lands would be to develop a decision-support system in order to improve how land in the Great Plains is managed. This tool will help landowners decide how best to use their land for the mutual benefit of their operations and natural systems. This will not be easy, as it will require looking at profitability while considering the critical times for all species and for different systems of land use. The decisions made will certainly differ by area, and the particular strategy of land use for each area will vary. This decision-support system must also recognize the dynamic nature of natural systems, and allow for continual evaluation of management decisions as conditions change in order to make necessary alterations to adjust for the desired outcome. If climate change causes a shift in crops or practices on the land, it is important to look at the reproductive cycles of the animals in relation to the critical periods for the new crops or practices. If these items are monitored as conditions change, many problems can be avoided.

Another coping strategy could be to suggest mechanisms to bring people together who have knowledge about the systems involved. This could result in landowners knowing more about natural systems, conservationists understanding more about agricultural systems, the possible development of a land stewardship program, and a broader understanding among the whole community in order to facilitate decision making that will consider the whole ecosystem. Workshops should be encouraged where people can look at the land and what happens naturally, and then develop plans based on what is a good ecological fit in that particular area.

A third coping strategy is innovation, e.g. giving land managers incentives to preserve habitats and protect endangered species. Land managers need to be involved in the very beginning in establishing policy. These policies need to result in positive incentives to produce pride in having endangered species, not negative repercussions for having these species on private land.

And last, a coping strategy that increases the diversity in agricultural operations will benefit wildlife, as well as farmers and ranchers. Diversity can help buffer operations from both climatic conditions and economic trends, either of which can put operations in economic stress. Diversification, such as having some pasture land in an alfalfa farming operation, can provide critical habitat for wildlife when haying must be done, and it can provide an alternate source of income if the alfalfa crop is destroyed due to hail, for example.

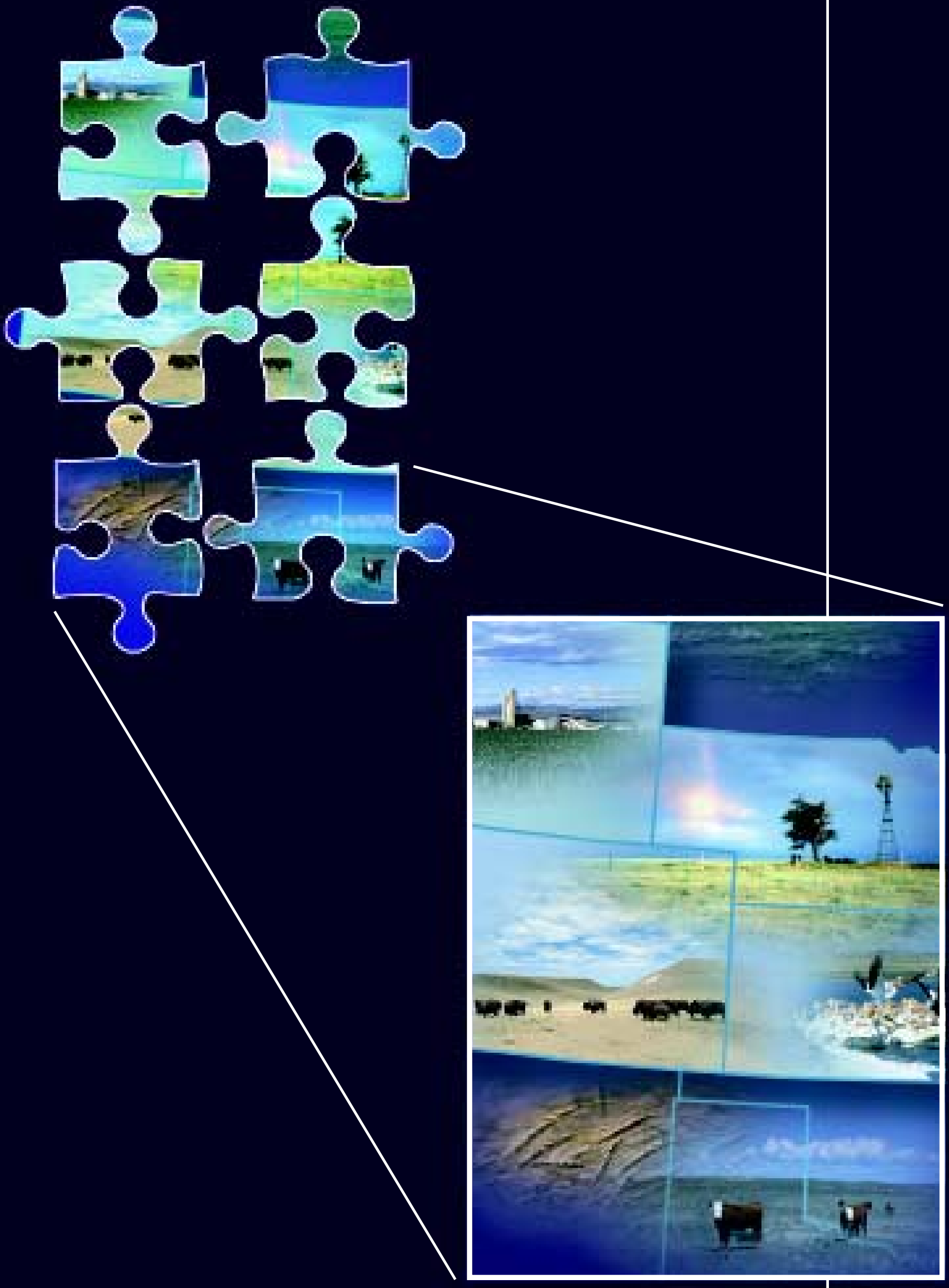
There may also be the potential to create cooperatives within communities so that operations can be diversified without one operator having to focus on everything. This will help people diversify who do not necessarily have the knowledge or cash flow to do it on their own. Within the market system it already operates this way; corn growers lease out their stubble for grazing and cattle are finished on corn. Many farmers and ranchers may still be too independent for this, but it may be a direction to move towards in order to foster sustainability. Friends and neighbors can help each other out during extreme events by sharing resources.

Livestock operations have some resilience built in, especially if they are spatially diverse. If ranchers can move their cattle to another place when they are experiencing drought, it will buffer them from extreme events. Therefore, the risk is transferred to another area when livestock are moved. With diversification of land use in a range operation, there can be conserved areas in the range. If there are some reserves that are not stocked to capacity all the time, dry periods may be survived. Rotations for lands in non-permanent grass areas are important. It is important to recognize, however, that every operation does not work the same way. For the sake of biodiversity, there needs to be some heavily grazed and some lightly grazed lands for habitat. It is a benefit to an operator to have patchiness on his/her place. This way, the operators can buffer themselves and the wildlife. Diversity in agricultural management techniques leads to diversity of wildlife and greater environmental stability.

Diversification can also include other techniques. There may be opportunities for recreation, such as bed and breakfasts on farms and ranches. The farmer/rancher does not necessarily have to guide tours him or herself. A tour guide could be an employee or another family member, while the farmer or rancher is free to continue with the primary operation.

CHAPTER 9:

PLANNING FOR THE 21ST CENTURY



Planning for the 21st Century

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It is recognized by members of this assessment that the recommendations that we make today will not necessarily apply ten years from now. Therefore, it is imperative to keep abreast of new and changing technology and the trend of the future climate, and to periodically reevaluate the risks and impacts of coping in order to truly make informed recommendations for adaptation.

Policy Recommendations

As stated previously, many systems in the Great Plains are already experiencing environmental stresses that continue to increase the vulnerability of these systems. By evaluating and using this information, it is possible that an adaptive management "action plan" can be developed to address current stressors and projected stressors across systems. This can begin today with what is already known. Caution should be taken to create management and policy systems that are multidisciplinary in approach and developed in collaboration with stakeholders, academicians, economists, policy makers, and other concerned groups with expertise and applied experience in management strategies. As with all environmental policies, considerable effort should be placed on beginning the policy development process with the stakeholders most closely involved and affected by the eventual implementation of policy directives.

Communications and policies should focus on landowners to promote strategies. To assist landowners in carrying out their charge, policies should promote the ability of landowners to be good stewards of their systems. Through incentives and the removal of existing barriers, stewardship can be supported and produce favorable results. By providing the right incentive(s) the market has the knowledge, the experience, and the ability to take care of itself.

Specific recommendations include:

1) Reevaluating agricultural programs to understand their intended and unintended consequences for ecosystems and human communities.
2) Investigate carbon credits as a possible financial incentive for promoting practices that encourage soil conservation and carbon sequestration. Continued research into the economics and logistics of implementing carbon credits, and identifying which practices might be targeted as most promising for sequestering carbon, are needed. To date, discussions on viable sequestration systems have focused on forests and soils. Grasslands and wetlands should also be included as potential carbon sinks and part of the agricultural contribution to mitigating atmospheric carbon levels. Consideration should be given to conducting a thorough economic analysis to determine the viability of agriculture's participation in a carbon banking system.
3) Any government policy directed towards responding to climate change should focus on the long-term, not on short-term economic incentives; should be flexible, allowing for local implementation and short response times; and should promote coping strategies that are sustainable and economically viable. Research is needed to more fully understand climate change and possible impacts for the Great Plains, including how to use the information to develop coping strategies for possible changes.

Future Research/Information Needs

There are many critical research and information needs in order to better understand the potential impacts of climate change in the Great Plains. These include:

1) Better information and information dissemination to stakeholders regarding climate change. This involves a flow of information and communication among stakeholders, scientists, and policy-makers.
2) Better forecasting of and preparation for extreme events, including hail storms.
3) Decision-support tools which facilitate appropriate decision-making need to be further researched.
4) Possible diversification strategies under a changing climate need to be researched.
5) Research into the valuation of carbon and possible sequestration strategies needs to be conducted if the issue of carbon credits is to come to fruition in the future.
6) New crops, crop varieties, and animal species should be evaluated to take advantage of a changed climate.
7) Possible new water storage locations should be identified in case they are needed in a changed climate regime.
8) More research into the effects of climate change on pests and disease vectors would be useful for coping with changed conditions.
9) Research to understand the function and health of ecological processes needs to be undertaken in order to cope with changed conditions.
10) Both direct and indirect effects of climate change on domestic livestock needs to be better understood.

11) Ecological and physiological thresholds of organisms and plants, including tolerances to different climatic factors should be studied further.

12) The cumulative effects of multiple stressors on organisms and ecosystems needs to be further studied.

13) Research on the best methods of restoration for damaged areas should be researched in order to be ready to work on restoring areas that are damaged by a changed climate, if restoration is possible or feasible.

14) A synthesis of current knowledge in an understandable and concise format will facilitate understanding of what is known and where more research is needed.

Conclusions

- There is a strong likelihood that the Great Plains will be a warmer place in the future. The precipitation pattern in the future is uncertain, with areas of both increased and decreased precipitation in the region. The potential warming and altered precipitation regime could have serious impacts for ecosystems and agriculture in the Great Plains.
- There will be both favorable and unfavorable consequences of changing climate in the future. For example, productivity of crops and grasses in the region may increase due to atmospheric carbon dioxide fertilization, whereas decreased soil moisture may decrease productivity.
- Invasive species and shifting ecosystems will be important to monitor in the future.
- Water resource declines, and competition among water users, may increase in the future due to the pattern of altered precipitation and warming, and the development in many areas of the region.
- Various coping strategies already exist in the region due to the need to deal with historic events involving climate variability. Farmers and ranchers in the region have proved themselves to be very adaptive historically. In addition, many adaptive management strategies used today are appropriate to deal with the more complex interactions between broader societal goals (urban, conservation, community issues) and greater environmental constraints (water competition, agricultural programs, water and air quality issues).
- Coping or adaptation strategies should be flexible and responsive to changing ecological and social trends. No regrets strategies that would be beneficial whether or not the climate shifts in a certain direction are advocated.
- Extreme events, seasonal patterns, and variability are important to consider (more than just changes in means).
- The rate of the potential changes are especially important when trying to cope, especially when adaptation involves a change of management where additional research/knowledge may be needed.
- Not all change will necessarily happen gradually. There could be some surprises, or rapid change events.
- Diversification may be a key to coping with potential climatic changes.
- Community-based adaptive management is important to stakeholders for future planning.
- Decision-making aids for land managers will be extremely important when coping with or adapting to climate change.
- There is still much uncertainty about the magnitude of climate change and the impacts of those changes.

SOME THOUGHTS AND GUIDANCE ON POLICY AND CLIMATE CHANGE RESEARCH

1. Thoughts

As a start, we define "policy" and discuss why it is important to this assessment. Policy is a course of action adopted in order to achieve a goal in a manner consistent with procedural values or restrictions. It is general guidance on how to proceed to achieve a goal or objective. Staying within the law and the budget are obvious policies; such policies restrict the courses one could take to achieve an objective. A policy issue might be whether to do a job in-house or contract out. NASA conducts most of its space activities through contractors, pursuant to policy guidance in its founding legislation. The policy issues in climate change are still unclear, with most actors originally assuming the underlying issues to be (i) whether the threat of anthropogenic climate change is real and (ii) if so, how to prevent or mitigate it. This second issue is a question of policy. A third, perhaps more important, policy issue emerges as we realize that past actions and decisions may have already committed us to a certain amount of change – the issue becomes how to adapt to unavoidable climate variability and change.

An assumption in this discussion is that the Federal government supports research on climate change primarily in hope of obtaining information to support policy decisions, and that is why we need to discuss policy. The policy issues of how to mitigate or adapt to climate change inevitably uncover conflicting interests. For example, if carbon dioxide emissions are to be reduced to mitigate climate change, fossil fuel industries will lose revenues, and so they oppose such reductions. Choosing a policy path to reduce carbon dioxide emissions will be contentious, and so policies will inevitably be involved, for a democracy resolves conflicts of values through politics. There is no way to avoid politics, research alone cannot dictate the best way to resolve such conflicts.

Conducting research to support policy is more complicated than merely doing good science. The scientist must understand the policy issues and not let research trajectories foreclose policy options. For example, such a foreclosure seems to have occurred due to the close coupling between research on whether climate change is anthropogenic and real (issue (i) above), and research on how to mitigate climate change (issue (ii)). If burning fossil fuels causes negative impacts by changing climate, then reducing such emissions seems an obvious way to mitigate the negative impacts. That is, research useful in identifying and characterizing the threat also suggests ways to reduce its impacts. This coupling also seems to imply a policy path of centralized control of emissions, which ignores both decentralized reduction of emissions (Brunner 1996, Brunner and Klein 1999) and adaptation to climate change (Pielke 1998), both of which call for very different programs of supporting research. The point here is that the scientific momentum in research programs originally focused on the useful goal of identifying the threat of climate change may have diverted the policy debate into a narrow discussion of centralized control by obscuring other important decentralized policy alternatives (which might demand the funding of different research). In other words, current research activities may be undermining good policy more than supporting it.

Policy decisions are always made with imperfect information, i.e., with uncertainty. For example, we do not know for sure whether a particular mitigation strategy will work. And decisions taken now consistent with current societal values may look foolish later as our values change. Finally, there is always some uncertainty in the science base, and in the case of climate change, in many areas the uncertainty is significant as the science continues to evolve. This argues against a large scale, centralized approach to climate change.

Unavoidable uncertainty also argues for what we might call "exploratory decision making." Scientists have long understood the value of "exploratory research" to discover novel solutions to problems. The same can be true for policy discussions, that is, novel approaches to mitigation or adaptation can be tried on a small scale to learn what works. Such experiments must necessarily be decentralized, local, reversible, and to be useful, susceptible to timely evaluation. Adaptation, being inherently local, will generate many candidates for such experiments. The successful experiments would be tried in other places, perhaps with modifications for local circumstances. All would not succeed, but there would be a high probability of some local successes which would be available for others to modify and try. After a few generations a "library" of evaluated and documented techniques would be available for use. The library (and a plan for disseminating information about the experiments) might be the only centrally directed activity (but see suggestion 2 below). Such practical, exploratory policy development would be a new departure in climate change research (Brunner 1991, Brunner 1996).

2. Guidance

This introductory discussion leads to some general suggestions on climate change research and policy.

Suggestion 1. Be flexible, resilient, nimble. Diversify activities and approaches, including research. Preserve the options of people in the field, especially in government policies. For example, farm operators should be prepared to try new crops and/or livestock and practices. Take advantage of new information and also use trials to generate new information.

Suggestion 2. Coordinate, communicate, decentralize. This is mostly about information generation and dissemination. The preferred model of information exchange is a web, not a hub with spokes. Centralization tends to segregate information. Take advantage of land managers as a source of practical information. Distribute information that increases the flexibility of land managers. Acknowledge that the information that some types of research can contribute to policy decisions is limited (it is limited to scientific knowledge, and may have little to say about reconciling opposing values).

Suggestion 3. Study incentives in the system. Recognize what overt and hidden incentives in the system really do, and separate this from what they are intended to do or what one wishes they would do. For example, what incentives drive soil organic matter down, and what could drive it up? Be realistic – more Federal dollars may not be a likely option, while on the other hand eliminating Federally-funded incentives that drive soil organic matter down would be welcome.

Suggestion 4. Examine assumptions, and look for the hidden ones. For example, an undiscussed assumption is that there will always be enough food and water for the cities. A more obscure assumption is that both food and water will always be inexpensive enough to supply the whole population at a similar level to what they are accustomed to. Another assumption is that science and technology will find answers for us. We know from experience that new information may not be perfect.

Suggestion 5. Evaluate activities in terms of progress in solving practical problems. For example, scientific or technical elegance per se is inadequate, good science is necessary but not sufficient. Evaluation must be in terms of practical results that stakeholders can validate.

3. Conclusion

Consideration of climate change from a practical perspective leads to suggestions for making policy progress.

References

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Albrecht, D.E. 1993. The renewal of population loss in the nonmetropolitan Great Plains. Rural Sociology. 58(2):233-246.

Alward, R.D., J.K. Detling, and D.G. Milchunas. 1999. Grassland vegetation changes and nocturnal global warming. Science. 283:229-231.

Archer, S., D.S. Schimel, E.S. Holland. 1994. Mechanisms of shrubland expansion: Land use, climate, or CO_2? Climatic Change. 21:91-99.

Baltensperger, B.H. 1987. Farm consolidation in the northern and central states of the Great Plains. Great Plains Quarterly. 7:256-265.

Barkema, A. and M. Drabenstott. 1996. Consolidation and change in heartland agriculture. Economic Forces Shaping the Rural Heartland. pp. 61-76. Kansas City: Federal Reserve Bank of Kansas City.

Barry, R.G. 1983. Climatic environment of the Great Plains, Past and present. Transactions of the Nebraska Academy of Science. XI (Special Issue):45-55.

Bergen Ministerial Declaration on Sustainable Development in the ECE Region, held in Bergen, Norway, 16 May 1990.

Blouet, B.W. and F.C. Luebke, eds. 1979. Introduction. The Great Plains: Environment and Culture. pp. ix-xxviii. Lincoln: University of Nebraska Press.

Boer G.J., G.M. Flato, and D. Ramsden. 2000. A transient climate change simulation with greenhouse gas and aerosol forcing: Projected climate to the twenty-first century. Climate Dynamics. 16(6):427-450.

Brunner, R.D. 1991. Global climate change: Defining the policy problem. Policy Sciences. 24:291-311.

Brunner, R.D. 1996. Policy and global change research: A modest proposal. Climatic Change. 32:121-147.

Brunner, R.D. and R. Klein. 1999. Harvesting experience: A reappraisal of the U.S. climate change action plan. Policy Sciences. 32:133-161.

Bunkers, M.J., J.R. Miller, and A.T. DeGaetano. 1996. An examination of El Niño-La Niña related precipitation and temperature anomalies across the Northern Plains. Journal of Climate. 9:147-160.

Burke, I.C., W.K. Lauenroth, W.J. Parton, and C.V. Cole. 1994. Interactions of landuse and ecosystem structure and function: A case study in the Central Great Plains. P.M Groffman and G.E. Likens, eds. Integrated Regional Models: Interactions Between Humans and their Environment. pp. 79-95. New York: Chapman and Hill.

Center for Agricultural and Rural Development. 1993. Symposium summary – conservation of Great Plains ecosystems: Current science and future options. United States Environmental Protection Agency. 21 pages.

Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. Cleaveland. 1999. Drought reconstructions for the continental United States. Journal of Climate. 12:1145-1162.

Covich, A.P., S.C. Fritz, P.J. Lamb, R.D. Marzolf, W.J. Matthews, K.A. Poiani, E.E. Prepas, M.B. Richman, and T.C. Winter. 1997. Potential effects of climate change on aquatic ecosystems of the Great Plains of North America. Hydrological Processes. 11:993-1021.

Dai, A., K.E. Trenberth, and T.R. Karl. 1998. Global variations in droughts and wet spells: 1900-1995. Geophysical Research Letters. 25:3367-3370.

Drabenstott, M. and T.R. Smith. 1996. The changing economy of the rural heartland. Economic Forces Shaping the Rural Heartland. pp. 1-11. Kansas City: Federal Reserve Bank of Kansas City.

Duncan, M., D. Fisher, and M. Drabenstott. 1995. Planning for a sustainable future in the Great Plains. D.A. Wilhite, D.A. Wood, and K.H. Smith, eds. Proceedings of the Symposium – Planning for a Sustainable Future: The Case of the North American Great Plains. pp. 23-42. IDIC Technical Report Series 95-1.

Fixico, D.L. 1985. Tribal leaders and the demand for natural energy resources on reservation lands. P. Iverson, ed. The Plains Indians of the Twentieth Century. pp. 219-235. Norman: University of Oklahoma Press.

Flato, G.M., G.J. Boer, W.G. Lee, N.A. McFarlane, D. Ramsden, M.C. Reader, and A.J. Weaver. 2000. The Canadian Centre for Climate Modelling and Analysis global coupled model and its climate. Climate Dynamics. 16(6):451-467.

Forman, S.L., R. Oglesby, and R.S. Webb. 2001. Temporal and spatial patterns of Holocene dune activity on the Great Plains of North America: Megadroughts and climate links. Global and Planetary Change. 29:1-29.

Hahn, L. and J. Morgan. Potential consequences of climate change on ruminant livestock production. Paper presented at the Rangelands and Climate Change Symposium at the 1999 Society for Range Management meeting. Omaha, Nebraska. February 25, 1999.

Hargreaves, M.W.M. 1993. Dry Farming in the Northern Great Plains: Years of Readjustment, 1920-1990. Lawrence, KS: University Press of Kansas.

Houghton, J. 1997. Global Warming: The Complete Briefing. 2nd edition. Cambridge: Cambridge University Press.

Johns, T.E., R.E. Carnell, J.F. Crossley, J.M. Gregory, J.F.B. Mitchell, C.A. Senior, S.G.B. Tett, and R.A. Wood. 1997. The second Hadley Centre coupled ocean-atmosphere GCM: Model description, spinup and validation. Climate Dynamics. 13:103-134.

Joyce, L.A., D. Ojima, G.A. Seielstad, R. Harriss, and J. Lackett. 2001. Potential consequences of climate variability and change for the Great Plains. National Assessment Synthesis Team. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Report for the US Global Change Research Program. pp. 191-217. Cambridge: Cambridge University Press.

Kittel, T.G.F., N.A. Rosenbloom, T.H. Painter, D.S. Schimel, and VEMAP Modeling Participants. 1995. The VEMAP integrated database for modeling United States ecosystem/vegetation sensitivity to climate change. Journal of Biogeography. 22:857-862.

Kittel, T.G.F., J.A. Royle, C. Daly, N.A. Rosenbloom, W.P. Gibson, H.H. Fisher, D.S. Schimel, L.M. Berliner, and VEMAP2 Participants. 1997. A gridded historical (1895-1993) bioclimate dataset for the conterminous United States. Proceedings of the 10th Conference on Applied Climatology, 20-24 October 1997, Reno, NV. pp. 219-222. Boston: American Meteorological Society.

Kittel, T.G.F., N.A. Rosenbloom, C. Kaufman, J.A. Royle, C. Daly, H.H. Fisher, W.P. Gibson, S. Aulenbach, R. McKeown, D.S. Schimel, and VEMAP2 Participants. 2000. VEMAP Phase 2 Historical and Future Scenario Climate Database. ORNL Distributed Active Archive Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

Lackett, J.M. 1998. New Measures of Conservation in Weld County, Colorado Agriculture. Master's Thesis. Colorado State University, Fort Collins, CO.

Licht, D.S. 1997. The waning rural economy. Ecology and Economics of the Great Plains. pp. 105-117. Lincoln: University of Nebraska Press.

Loveland, T.R., J.W. Merchant, D.O. Ohlen, and J.F. Brown. 1991. Development of a land-cover characteristics database for the conterminous U.S. Photogrammetric Engineering and Remote Sensing. 57(11):1453-1463.

Miller, K. 1997. Climate variability, climate change, and western water. Report to the Western Water Policy Review Advisory Commission. National Technical Information Service. Springfield, VA. see also http://www.den.doi.gov/wwprac/reports/west.htm.

Mitchell, J.F.B., T.C. Johns, J.M. Gregory, and S. Tett. 1995. Climate response to increasing levels of greenhouse gases and sulfate aerosols. Nature. 376:501-504.

National Interagency Fire Center. 2001. http://www.nifc.gov/stats/historicalstats.html.

National Assessment Synthesis Team. 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Report for the US Global Change Research Program. Cambridge: Cambridge University Press.

Norwood, C.A. 2000. Water use and yield of limited-irrigated and dryland corn. Soil Science Society of America Journal. 64:365-370.

NPA Data Services, Inc. 1998. Regional Economic Projections Series. Washington, DC.

NRCS, Northern Plains Regional Office. 1996. State of the Land for the Northern Plains Region. USDA NRCS, Northern Plains Regional Office. Lincoln, NE. 64 pages.

NRI, NRCS, USDA. 1997. http://www.nhq.nrcs.usda.gov/land/home.html.

Office of Science and Technology Policy. 1997. Climate Change: State of Knowledge. Washington, D.C.

Ojima, D., L. Garcia, E. Elgaali, K. Miller, T.G.F. Kittel, and J. Lackett. 1999. Potential climate change impacts on water resources in the Central Great Plains. Journal of the American Water Resources Association. 35(6):1-12.

Parton, W.J., J.W.B. Stewart, and C.V. Cole. 1988. Dynamics of C, N, P, and S in grassland soils: A model. Biogeochemistry. 5:109-131.

Parton, W.J., D.S. Ojima, and D.S. Schimel. 1994. Environmental change in grasslands: Assessment using models. Climate Change. 28:111-141.

Pielke, R.A. 1998. Rethinking the role of adaptation in climate policy. Global Environmental Change. 8:159-170.

Polley, H.W., H.B. Johnson, and H.S. Mayeux. 1992. Increasing CO_2: Comparative responses of the C_4 grass Schizachyriuim and grassland invader Prosopis. Ecology. 75:976-988.

Riebsame, W.E. 1990. The United States Great Plains. B.L. Turner II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer, eds. The Earth as Transformed By Human Action: Global and Regional Changes in the Biosphere Over the Past 300 Years. pp. 561-575. Cambridge: Cambridge University Press.

Rosenzweig, C. and D. Hillel. 1995. Potential impacts of climate change on agriculture and food supply. Consequences: The Nature and Implications of Environmental Change. 1(2):22-32.

Ryan, K.C. 1991. Vegetation and wildland fire: Implications of global climate change. Environment International. 17(2-3):169-178.

Shepard, L. 1986. The farm debt crisis: Temporary or chronic? Contemporary Economic Policy. 4:62-71.

Skold, M.D. 1995. Agricultural systems and economic characteristics of the Great Plains. S.R. Johnson and A. Bouzaher, eds. Conservation of Great Plains Ecosystems: Current Science, Future Options. pp. 343-364. Boston: Kluwer Academic Publishers.

Smit, B., D. McNabb, and J. Smithers. 1996. Agricultural adaptation to climatic variation. Climatic Change. 33:7-29.

Stabler, J.C. and M.R. Olfert. 1993. Farm structure and community viability in the northern Great Plains. The Review of Regional Studies. 23:265-286.

Ting, M.F. and H. Wang. 1997. Summertime United States precipitation variability and its relation to Pacific sea surface temperatures. Journal of Climate. 10:1853-1873.

Trenberth, K.E. and C.J. Guillemot. 1996. Physical processes involved in the 1988 drought and 1993 floods in North America. Journal of Climate. 9:1288-1298.

University of Texas Population Research Center. 1998. Great Plains Population and Environment Database: Version 1.0. Austin, Texas: Population Research Center, University of Texas at Austin.

USA Counties 1996. U. S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census.

USDA, Soil Conservation Service, 1970. Irrigation Water Requirements. Tech Release No. 21, (rev.), 92 pp.

USDA. 1986. Fact Book of Agriculture. Miscellaneous Publication No. 1063.

USDA Census of Agriculture. 1992. National Agricultural Statistics Service.

USDA Census of Agriculture. 1997. National Agricultural Statistics Service.

US Department of Commerce. 1998. Bureau of Economic Analysis. Regional Economic Analysis Division.

Walters, C. and C. J. Fenzau. 1979. An Acres U.S.A. Primer. Acres U.S.A., Raytown, MO.

Wolter, K., R.M. Dole, and C.A. Smith. 1999. Short-term climate extremes over the continental U.S. and ENSO. Part I: seasonal temperatures. Journal of Climate. 13:3255-3272.

Acronyms Used

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AET – actual evapotranspiration
CCC – Canadian Climate Centre
CRP – Conservation Reserve Program
CU – consumptive use
DSS – decision support systems
ENSO – El-Niño Southern Oscillation
ESA – Endangered Species Act
ET – evapotranspiration
FSA – Farm Service Agency
GCM – general circulation model
HAD – UKMO-Hadley model
IWR – irrigation water requirements
NAST – National Assessment Synthesis Team
NPP – net primary production
NRCS – Natural Resources Conservation Service
OSTP – Office of Science and Technology Policy
PDSI – Palmer Drought Severity Index
PET – potential evapotranspiration
PPT – precipitation
SOI – Southern Oscillation Index
USDA – United States Department of Agriculture
USGCRP – US Global Change Research Program
VEMAP – Vegetation/Ecosystem Modeling and Analysis Project

APPENDICES

Appendix A: Participants

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Steering Committee and Assessment Team

Dennis Ojima, Colorado State University
Jill Lackett, Colorado State University
Lenora Bohren, Colorado State University
Dennis Child, Colorado State University
Alan Covich, Colorado State University
Kathy Galvin, Colorado State University
Luis Garcia, Colorado State University
Jim Geist, Colorado Corn Administrative Committee
Myron Gutmann, University of Michigan (formerly of the University of Texas at Austin)
LeRoy Hahn, USDA-ARS
Tom Hobbs, Colorado State University
Linda Joyce, US Forest Service
Timothy G. F. Kittel, National Center for Atmospheric Research (NCAR)
Martin Kleinschmit, Center for Rural Affairs
Kathy Miller, National Center for Atmospheric Research (NCAR)
Jack Morgan, USDA-ARS
Bill Parton, Colorado State University
Keith Paustian, Colorado State University
Gary Peterson, Colorado State University
Rob Ravenscroft, Rancher
Jorge Ramirez, Colorado State University
Lee Sommers, Colorado State University
Bill Waltman, National Resources Conservation Service (NRCS)
Robert S. Webb, National Oceanic and Atmospheric Administration (NOAA) Climate Diagnostics Center

Sectoral Group Leaders

Range and Livestock – Dennis Child, Jack Morgan, LeRoy Hahn
Crop – Gary Peterson, Lee Sommers
Water – Luis Garcia, Kathy Miller
Conservation – Tom Hobbs, Alan Covich

Conveners and Rapporteurs – Sylvan Dale Workshop 1999

Range and Livestock – Jack Morgan (convener), Rod Heitschmidt/June Rain (rapporteurs)
Crop – Gary Peterson (convener), Jill Lackett (rapporteur)
Water – Luis Garcia and Kathy Miller (conveners), Lenora Bohren (rapporteur)
Conservation – Tom Hobbs and Alan Covich (conveners), Phyllis Breeze (rapporteur)

Authors of Sectoral Group Reports

Range and Livestock – Jack Morgan, Kathy Galvin
Crop – Jill Lackett, Martin Kleinschmit
Water – Lenora Bohren, Kathy Miller, Luis Garcia
Conservation – Phyllis Breeze, Tom Hobbs

Workshop Participants

Central Great Plains Regional Assessment Scoping Workshop

May 27-29, 1997

Sylvan Dale Guest Ranch – Loveland, CO

John Altenhoffen, Northern Colorado Water Conservancy District
John Antle, Montana State University
Jill Baron, Colorado State University
Susan Bassow, Office of Science and Technology Policy
Walt Berg, Recom Applied Solutions
George Bluhm, University of California
Lenora Bohren, Colorado State University
Phyllis Breeze, Colorado Department of Public Health & Environment
Jesslyn Brown, USGS EROS Data Center
Radford Byerly, Science & Technology Policy
David Cash, Harvard University
Vern Cole, Colorado State University
Kevin Dennehy, USGS
Mark Drabenstott, Federal Reserve Bank of Kansas City
William Easterling, The Pennsylvania State University
Sylvia Edgerton, US Department of Energy
Stacey Eriksen, EPA Region 8
Jody Farhat, Army Corp of Engineers
Ron Follett, USDA-ARS
Diana Wall, Colorado State University
Luis Garcia, Colorado State University
Jim Geist, Colorado Corn Administrative Committee
Lewis Grant, Piedmont Farms, Inc.
Judson Harper, Colorado State University
Ron Hiebert, Midwest Region – National Park Service
Ken G. Hubbard, University of Nebraska-Lincoln
Richard Johnson, USDI-USGS-Biological Resources Division
Linda Joyce, US Forest Service
John Kermond, NOAA-Office of Global Programs
Martin Kleinschmit, Center for Rural Affairs
Clara Kustra, University of New Hampshire
Forrest Leaf, Central Colorado Water Conservancy District
Gilbert Lindstrom, Farmer
Linda Mearns, National Center for Atmospheric Research
Jerry Melillo, Office of Science and Technology Policy
Ann Mesnikoff, Sierra Club
Lynn Mortensen, PCSD/ES

Betsy Neely, The Nature Conservancy of Colorado
Dennis Ojima, Colorado State University
Bill Parton, Colorado State University
Keith Paustian, Colorado State University
Fred Quartarone, Colorado Department of Public Health & Environment
James Quick, Colorado State University
Jorge Ramirez, Colorado State University
Rob Ravenscroft, Rancher
William Reiners, University of Wyoming
Ken Remington, Farmer
William Riebsame, University of Colorado
Michael Sale, Oak Ridge National Laboratory
Dave Schafersman, Bureau of Land Management
David Schimel, National Center for Atmospheric Research
Mel Skold, Colorado State University
Joel Smith, Hagler Bailly Consulting, Inc.
Rey Stendell, USDI-USGS-Biological Resources Division
Melissa Taylor, Office of the United States Global Change Research Program (USGCRP)
Paul Tebbel, Rowe Sanctuary
Lori Triplett, The Great Plains Foundation
Jim Valliant, Colorado Cooperative Extension
Bruce Van Haveren, Bureau of Land Management
Christina Walters, Colorado State University
Bill Waltman, Natural Resources Conservation Service
Thomas J. Wilbanks, Oak Ridge National Laboratory
Timothy E. Wirth, Department of State
Robert Woodmansee, Larimer County Rural Land Use Board

Ranching and Livestock Focus Group Workshop

September 24-25, 1998

US Meat Animal Research Center - Clay Center, NE

Bob Baum, Rancher
Glen Baum, Rancher
Dennis Child, Colorado State University
Todd Deatrich, Rancher
Jerry Dodd, Cameron University
LeRoy Hahn, US Meat Animal Research Center
Martin Kleinschmit, Center for Rural Affairs
Walt Koziol, Rancher
Jill Lackett, Colorado State University
Jack Morgan, USDA-ARS Rangeland Resources
John A. (Jack) Nienaber, US Meat Animal Research Center
Dennis Ojima, Colorado State University
Rob Ravenscroft, Rancher
Brad Staab, Rancher
Paul Swanson, University of Nebraska-Lincoln

Water Focus Group Workshop

December 1-2, 1998

Sylvan Dale Guest Ranch - Loveland, CO

Jill Baron, Colorado State University
Alan Covich, Colorado State University
Jody Farhat, Army Corps of Engineers
Luis Garcia, Colorado State University
John Harrington, Jr., Kansas State University
Brian Hurd, Stratus Consulting, Inc.
Jill Lackett, Colorado State University
Kathy Miller, National Center For Atmospheric Research
Dennis Ojima, Colorado State University
Bill Parton, Colorado State University
Andy Pineda, Northern Colorado Water Conservancy District
Dick Stenzel, Colorado Division of Water Resources
Kenneth Strzepek, University of Colorado
Robert C. Ward, Colorado State University
David Yates, National Center for Atmospheric Research

Cropping Systems Focus Group Workshop

January 28-29, 1999

Colorado State University - Fort Collins, CO

Lenora Bohren, Colorado State University
D. Bruce Bosley, Colorado Cooperative Extension
Jill Lackett, Colorado State University
Gilbert Lindstrom, Farmer
Drew Lyon, University of Nebraska
Dennis Ojima, Colorado State University
Gary Peterson, Colorado State University
Alan Schlegel, Kansas State University
Lee Sommers, Colorado State University
Merle Vigil, USDA-ARS

Climate Change Impacts on Rangelands Systems Workshop

February 26, 1999

Society for Range Management Meeting - Omaha, NE

Bob Baum, Rancher
Klaas Broersma, Agriculture and Agri-Food Canada
Dennis Child, Colorado State University
Barb Cooksley, Rancher
Jerry Dodd, Cameron University
Virginia Emly, Nebraska National Forest
LeRoy Hahn, US Meat Animal Research Center
Linda Joyce, US Forest Service
Martin Kleinschmit, Center for Rural Affairs
Jill Lackett, Colorado State University
Frank LaMere, Earth, Energy, Environment Inc.

Terry Mader, UNL Northeast Research and Extension Center
Dennis Ojima, Colorado State University
Patrick Spears, Intertribal Council on Utility Policy
Bob Sprentall, Nebraska National Forest
Al Steuter, Nature Conservancy
Paul Swanson, Nebraska Cooperative Extension
Dale Weisbrot, Government of Saskatchewan

Conservation Focus Group Workshop

March 3, 1999

Colorado State University – Fort Collins, CO

David Cooper, Colorado State University
Alan Covich, Colorado State University
Wendell Gilgert, Colorado State University
Tom Hobbs, Colorado State University
Jill Lackett, Colorado State University
Dennis Ojima, Colorado State University
LeRoy Poff, Colorado State University

Central Great Plains Climate Change Impacts Assessment Workshop

March 22-24, 1999

Sylvan Dale Guest Ranch – Loveland, CO

Jon Altenhofen, Northern Colorado Water Conservancy District
Bob Baum, Rancher
Glen Baum, Rancher
Tom Bergner, Bergner Farms
Lenora Bohren, Colorado State University
Phyllis Breeze, Colorado Department of Public Health & Environment
Dale Bremer, Kansas State University
Radford Byerly, Science & Technology Policy
Sam Carroll, Farmer
David Cash, Harvard University
Jim Cederburg, Farmer
Dennis Child, Colorado State University
Alan Covich, Colorado State University
Jerry Dodd, Cameron University
Ned A. "Chip" Euliss, Northern Prairie Wildlife Research Center
Laura Farris, US EPA Region 8
Kurt Fausch, Colorado State University
Benjamin Felzer, National Center for Atmospheric Research
Kathy Galvin, Colorado State University
Luis Garcia, Colorado State University
Jim Geist, Colorado Corn Administrative Committee
Wendell Gilgert, Colorado State University
Bruce Gill, Colorado Division of Wildlife
Sylvia Gillen, Western Governor's Association
Greg Graff, Farmer
Myron Gutmann, The University of Texas at Austin
LeRoy Hahn, US Meat Animal Research Center
Rod Heitschmidt, USDA-ARS
Dave Hilferty, Farmer
Tom Hobbs, Colorado State University
Steve Hu, University of Nebraska
Marvin Jensen, Consumptive Use Specialist
Don Johnson, Colorado State University
Hoyt Johnson, Prescott College
Linda Joyce, US Forest Service
Tim Kittel, National Center for Atmospheric Research
Martin Kleinschmit, Center for Rural Affairs
John Kochendorfer, Colorado State University
James Krall, University of Wyoming
Jill Lackett, Colorado State University
Chris Lauver, Kansas Biological Survey
Forrest Leaf, Central Colorado Water Conservancy
Verne Leverson, US Bureau of Reclamation-River Systems & Meteorology Group
Carl Mattson, Farmer
Jon Medina, US Bureau of Reclamation-River Systems & Meteorology Group
Kathy Miller, National Center For Atmospheric Research
Paul Montoia, City of Hays, KS
Jack Morgan, USDA-ARS Rangeland Resources
Dennis Ojima, Colorado State University
Will Orr, Prescott College
Bill Parton, Colorado State University
Gary Peterson, Colorado State University
June Rain, Cameron University
James Rattling Leaf, Sinte Gleska University
Rob Ravenscroft, Rancher
Gene Reetz, US EPA Region 8
Alan Schlegel, Kansas State University
Gerald Schuman, USDA-ARS
George Seielstad, University of North Dakota
Lisa Colombe Simon, Sinte Gleska University
Patrick Spears, Intertribal Council on Utility Policy
Dick Stenzel, Colorado Division of Water Resources
Paul Swanson, University of Nebraska-Lincoln
Merle Vigil, USDA-ARS
Stephen Waite, Dodge City Community College
Robert (Robin) Webb, NOAA-NGDC Paleoclimatology Program
Dwayne Westfall, Colorado State University
Jerry Winslow, University of Wyoming
Robert Woodmansee, Larimer County Rural Land Use Board
David Yates, National Center for Atmospheric Research

Appendix B: National Assessment of the Consequences of Climate Variability and Change for the United States

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The influence of climate permeates life and lifestyles in the U.S. Year-to-year variations are reflected in such things as the number and intensity of storms, the amount of water flowing in our rivers, the extent and duration of snow cover, and the intensity of waves that strike our coastal regions. Science now suggests that human activities are causing the climate to change. Although the details are still hazy about how much the changes will be in each region of the country, changes are starting to become evident. Temperatures have increased in many areas, snow cover is not lasting as long in the spring, and total precipitation is increasing, with more rainfall occurring in intense downpours. These changes appear to be affecting plants and wildlife. There is evidence of a longer growing season in northern areas and changing ranges for butterflies and other species. The international assessments of the Intergovernmental Panel on Climate Change (http://www.ipcc.ch) project that these changes will increase over the next 100 years.

The Global Change Research Act of 1990 [Public Law 101-606] gave voice to early scientific findings that human activities were starting to change the global climate: "(1) Industrial, agricultural, and other human activities, coupled with an expanding world population, are contributing to processes of global change that may significantly alter the Earth habitat within a few generations; (2) Such human-induced changes, in conjunction with natural fluctuations, may lead to significant global warming and thus alter world climate patterns and increase global sea levels. Over the next century, these consequences could adversely affect world agricultural and marine production, coastal habitability, biological diversity, human health, and global economic and social well-being."

To address these issues, Congress established the U.S. Global Change Research Program (USGCRP) and instructed the Federal research agencies to cooperate in developing and coordinating "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural process of global change." Further, the Congress mandated that the USGCRP "shall prepare and submit to the President and the Congress an assessment which

1) integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings;
2) analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and
3) analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years." The USGCRP's National Assessment of the Potential Consequences of Climate Variability and Change, which is focused on answering the question about why we should care about and how we might effectively prepare for climate variability and change, is being conducted under the provisions of this Act.

The overall goal of the National Assessment is to analyze and evaluate what is known about the potential consequences of climate variability and change for the Nation in the context of other pressures on the public, the environment, and the Nation's resources. The National Assessment process has been broadly inclusive, drawing on inputs from academia, government, the public and private sectors, and interested citizens. Starting with broad public concerns about the environment, the Assessment is exploring the degree to which existing and future variations and changes in climate might affect issues that people care about. A short list of questions has guided the process as the Assessment has focused on regional concerns around the US and national concerns for particular sectors:

- What are the current environmental stresses and issues that form the backdrop for potential additional impacts of climate change?
- How might climate variability and change exacerbate or ameliorate existing problems? What new problems and issues might arise?
- What are the priority research and information needs that can better prepare the public and policy makers for reaching informed decisions related to climate variability and change? What research is most important to complete over the short term? Over the long term?
- What coping options exist that can build resilience to current environmental stresses, and also possibly lessen the impacts of climate change?

The National Assessment has three major components:

1. Regional analyses: Workshops and assessments are characterizing the potential consequences of climate variability and change in regions spanning the US. A total of 20 workshops were held around the country, with the Native Peoples/Native Homelands workshop being national in scope rather than regional; to date, sixteen of these groups are proceeding to prepare assessment reports. The reports from these activities address the interests of those in the particular regions by focusing on the regional patterns and texture of changes where people live. Most workshop reports are already available (see http://www.nacc.usgcrp.gov) and assessment reports will start to become available in late 1999.
2. Sectoral analyses: Workshops and assessments are being carried out to characterize the potential consequences of climate variability and change for major sectors that cut across environmental, economic, and societal interests. The sectoral studies analyze how the consequences in each region affect the Nation, making these reports national in scope and of interest to everyone. The sectors being focused on in this first phase of the ongoing National Assessment include Agriculture, Forests, Human Health, Water, and Coastal Areas and Marine Resources. Many publications and assessment reports are already available.
3. National overview: The National Assessment Synthesis Team has responsibility for summarizing and integrating the findings of the regional and sectoral studies and then drawing conclusions about the importance of climate change and variability for the United States. Their report is now available.

Each of the regional, sectoral, and synthesis activities is being led by a team comprised of experts from both the public and private sectors, from universities and government, and from the spectrum of stakeholder communities. Their reports have all gone through an extensive review process involving experts and other interested stakeholders. The assessment process is supported in a shared manner by the set of USGCRP agencies, including the departments of Agriculture, Commerce (National Oceanic and Atmospheric Administration), Energy, Health and Human Services, and Interior plus the Environmental Protection Agency, National Aeronautics and Space Administration, and the National Science Foundation. Through this involvement, the USGCRP is hopeful that broad understanding of the issue and its importance for the Nation will be gained and that the full range of perspectives about how best to respond will be aired.

Extensive information about the assessment, participants on the various assessment teams and groups, and links to the activities of the various regions and sectors are available over the Web at http://www.nacc.usgcrp.gov or by inquiry to the Global Change Research Information Office, PO Box 1000, 61 Route 9W, Palisades, New York 10964.

Prepared by Michael MacCracken, National Assessment Coordination Office, Revised Oct. 5, 1999.

Appendix C: VEMAP, UKMO-Hadley, and Canadian Climate Centre Scenario Information

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The climate change analyses in this assessment are based on the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) historical climate and future scenario climate datasets (Kittel et al. 1995, Kittel et al. 1997, Kittel et al. 2000). These VEMAP scenarios are derived from the climate sensitivity experiments using the Canadian Climate Centre CGCMI model from the Canadian Centre for Climate Modeling and Analysis (CCC) (Boer et al. 2000) and the UK Hadley Centre HADCM2 model from the Hadley Centre for Climate Prediction and Research (Hadley) (Mitchell et al. 1995). Both models are coupled atmosphere-ocean general circulation models. In both models the historical concentration of greenhouse gases is used from the beginning of the run to the present, and the concentration of greenhouse gases increases 1 %/year after 1989. The effects of increasing levels of sulfate aerosols are also included in both models. In this assessment, the VEMAP 205-year climate dataset was composed of a 99-year historical record (observed climate), followed by a little over 100 years of simulated future climate (to 2100). The results of these two experiments are intended to provide a range of possible future climates for the region. Because there are many uncertain variables about the future, these analyses should only be used to look at plausible futures and impacts. They are not intended to be taken as predictions. A description of the CCC model can be found in Flato et al. (2000). A description of the Hadley model can be found in Johns et al. (1997). The VEMAP dataset is described on the web site *http://www.cgd.ucar.edu/vemap/* and is available online at the ORNL DAAC website *http://www.daac.ornl.gov/VEMAP/vemap.html* and the EOS-Webster website *http://eos-webster.sr.unh.edu/EOS/WEBSTER.*

Appendix D: Water Group Scenarios

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SCENARIO ONE

Precipitation early spring – April-May (rainfall decreases in July and August, the two months when the crops need the maximum amount of rain), normal amounts

General Critical Issues:

- Longer growing season due to warmer temperature
- Alluvial aquifer recharge (natural recharge)
- Increased flow in rivers – especially early season, but also possible total annual depending on evaporation of precipitation and aquifer recharge
- More spring runoff
- Less evaporation, soil will store more water

General Coping tactics/strategies:

- Enhance ways to store water – use dryland tactics such as stubble mulch, no-till, etc. on irrigated lands

Western Great Plains

Critical Issues:

- Less use of water in aquifer, i.e. less irrigation demand
- Recharge of aquifers

Coping tactics/strategies:

- Promote continuous wheat (from wheat fallow), i.e. annual cropping of wheat may increase yields
- Change in cropping patterns and the crops used
- Winter wheat planted in fall encouraged
- Change cropping to cool season crops from warm season crops
- If more hail, change to more hail-tolerant crop
- Dryland – move toward irrigation, those who couldn't would be in trouble, they would have to change crops (winter type of crop) to take advantage of rainfall (winter wheat)

Eastern Great Plains

Critical Issues:

- Extreme events, such as hail

Coping tactics/strategies:

- Safety mechanism – reservoirs (more natural recharge)

Irrigated Agriculture (Front Range):

Critical Issues:

- May cause an earlier and longer irrigation season
- Small increase in water demand
- Increase in water transfers from agricultural to municipal use
- Accelerated decrease in farms and area of irrigated farmland
- Income distribution effect (hitting the junior farmers harder than the senior farmers)
- Increase in water demand in the Great Plains
- ESA requirements

Coping tactics/strategies:

- Change in cropping to crops that need longer growing season, with or without additional water
- Land use for marginal agriculture units that are not irrigated will change, possibly marginal irrigators would sell some water rights, therefore marginal units may go out of production (water usually goes from agriculture to agriculture, although some agricultural water goes to urban uses in water transfers)
- Water banking
- Legal institutions will allow transfers of surplus waters to points of need
- Adopting new technology
- Better prediction of weather patterns
- More efficient use of water
- Decision support systems allowing educated selections of options
- Diversity of land use
- Change in forage patterns for wildlife
- Change in water stream temperatures may change biodiversity
- Sell water rights
- Meet local demands for products
- Generate legal institutions to allow transfers or trade during season

Non-Irrigated Agriculture:

- Eastern Great Plains: More moderate effect; may cause longer growing season
- Hotter temperatures may be a bigger concern

Critical Issues:

- Decline in output
- Decline in acreage
- Reduced profitability
- Limit viability of the land (cropland to rangeland)
- More of a population shift than the irrigated agriculture (Western and Eastern Great Plains)
- ESA requirements

Coping tactics/strategies:

- Change in cropping to crops that need less dormancy
- More or less hail and destructive storms
- No or minimum population changes
- Changes in water transfers will not be required
- Decision support systems allowing for educated selection of options
- Change in forage patterns for wildlife (ESA)
- Adding constructed wetlands
- No till agriculture

Urban:

- May have early season benefits such as less spring/early summer water use for maintaining lawns, but will require more mid-summer and summer water demand
- Early recharge of aquifers and/or reservoirs

Critical Issues:

- Increased late season lawn irrigation demand
- Increased transfer from agricultural to urban uses of water

Coping tactics/strategies:

- Change in lawn types; cool season grasses
- More or less hail damage and destructive storms; may cause economic construction impact
- No or minimum population changes; increased migration from rural to urban areas
- Conservation – change of values, people will become more conservation-minded
- Change in local ordinances and water use (i.e., change in permitted lawn types, lawn water periods, water pricing changes)

Recreation:

- May have seasonal benefits such as earlier sporting seasons; lake and river recharges will be noticeable

Critical Issues:

- Decreased levels in the reservoirs
- More clear days – more evaporation
- Maintenance of water levels
- Less variety of fish

Coping tactics/strategies:

- Adjusted attitude change; water belongs to the sportsman and they have first right

Power production:

Critical Issues:

- Less water available in cooling towers and hydropower
- Further loss of habitat

General Comments on Scenario 1:

- Longer growing season might invite species that adapt to this type of condition.
- There would be a greater demand on irrigation since precipitation is moving away from peak demand periods.
- There would be a greater impact on dryland systems than on irrigation systems since there is less precipitation during growing season.

Note – First order impacts are discussed above, 2nd and 3rd order impacts are often worse, such as, brown outs from hydroelectric power.

SCENARIO TWO

Precipitation late – August-September, normal amounts

General Critical Issues:

- Peak rainfall in August and September
- Previous season storage – over season storage for next season
- Possible harvesting problem because of wet crops – to remedy you would want to harvest in early August
- Dryland crops will be faced with hotter weather and more evaporation
- Irrigated crops will be faced with more demands on water when planting and at peak
- Plant earlier
- Irrigated agriculture (Front Range): little effect; may cause a shorter irrigation season

General Coping tactics/strategies:

- Change in cropping to crops that need shorter growing season or crops that can be started with minimal amounts of water
- Change in river flows of the South Platte River may change temperatures that change wildlife
- Population stress; land use for marginal agriculture units that are not irrigated may change
- Plant, species stress; may result in change of biodiversity
- Legal institutions will allow transfers of surplus waters to points of need
- Adopting new technology – better predicting of weather patterns
- More efficient use of early season water
- Change in hail patterns; may benefit economic construction
- More intense recharge events
- Decision support systems allowing educated selections of options
- Diversity of land use
- Change in forage patterns for wildlife
- Change in water stream temperatures may change biodiversity

There was little time left to discuss scenarios 3 and 4, but the information collected is discussed below.

SCENARIO THREE

More precipitation/snow

- More runoff and therefore increased water availability with likely positive impacts on agriculture, endangered species, urban water availability, and recreation

SCENARIO FOUR

Less precipitation

General Critical Issues:

- Drought
- Legal, social, and political constraints differing for different states
- Land use
- Recreation issues
- Power production
- Endangered species
- Increased irrigation requirements
- Decreased streamflow

General Coping tactics/strategies:

- Change in cropping patterns (wheat vs. corn)
- Change crops to cool season crops vs. warm season crops
- New species of crops

Appendix E: Range and Livestock Group Scenarios

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The following are examples of what ranchers might do under some specific climate events.

SCENARIO ONE

Future climate where temperatures increase, precipitation decreases, CO_2 increases, and the economy/policy is like it is now. This occurs within the next **10** years and forage is reduced by **25%.** Strategies/tactics include:

- diversify animals which might include sheep, bison, or wildlife
- diversify product ownership so that the cost of raising cattle is spread among groups; e.g., cooperative herd ownership or shipping to feedlots
- reduce debt and increase savings
- move towards a least-cost production strategy
- pay attention to global markets such as Australia, Canada, Argentina, and Brazil as potential competitors
- diversify market strategies, serve the increasing urban populations where possible

SCENARIO TWO

Future climate where temperatures increase, precipitation decreases, CO_2 increases, and the economy/policy is like it is now. This occurs in the next 40 years and forage is reduced by 75%. Strategies/tactics include:

- increase profitability per animal unit, as it is likely that water costs may be high and costs of production are also high
- increase specializations, such as direct marketing
- decrease the amount of land in crops and increase grazing lands (reseeding)

SCENARIO THREE

Future climate where temperatures increase, precipitation remains the same, CO_2 increases, and the economy/policy is like it is now. This occurs within the next 10 years and forage is increased by 25%. Strategies/tactics include:

- purchasing land
- intensifying management, such as putting more animals on the range, adding yearlings
- diversify land use, such as renting out land
- reduce debt and increase savings

SCENARIO FOUR

Future climate where temperatures increase, precipitation remains the same, CO_2 increases, and the economy/policy is like it is now. This occurs in the next 40 years and forage is increased by 75%. Strategies/tactics include:

- convert more land into cropland
- pay particular attention to global climate and economic conditions
- become more extensive in land use (use less intensive tactics regarding land use)

SCENARIO FIVE

Future climate where temperatures increase, precipitation remains the same, CO_2 increases, and the rural and regional economy is weak. This occurs within the next 10 years and forage is reduced by 25%. Strategies/tactics include:

- diversify into new enterprises, such as recreation, hunting, and bison ranching
- move into more extensive management
- pay attention to the global climate and economic situation
- move towards larger and fewer farms, often owned by non-local people

Ranchers are currently experimenting with some of these things in their operations when conditions dictate. What ranchers really need is information, such as a DSS (decision-support system), and good climate and weather knowledge that will allow them to adapt to changes. And, they need the freedom to be flexible in their management when required.

Appendix F: Metric Unit Tables

Chapter 2

Table 2-1: Annual Results: The range shows the deviations of the parameters from the baseline period (1961-1990) in the CCC and Hadley model scenario experiments.

Parameter	2030☆	2090
a. Average temperature (°C)	+1.6 to +2.2	+3.7 to +6.0
b. Average precipitation (mm)	-31.0 to +23.1	+81.4 to +119.0
c. Runoff (mm/yr)	-12.5 to +6.2	+12.4 to +34.0
d. Snowpack (cm)	-0.2 to -0.1	-0.4 to -0.2
e. Heat Events (3 or more days ≥38°C)	+1.2 to +1.4	+2.7 to +4.1
f. Hot Days (# of days ≥ 38°C)	+7.9 to +8.1	+20.8 to +34.0
g. Cold Days (# of days ≤ 0°C)	-36.5 to -26.7	-72.7 to -62.9
h. Growing Degree Days (7.2°C)	+354.1 to +414.1	+824.3 to +1323.3
i. Soil Carbon (g C/m^2)	-12.7 to -12.3	-3.0 to -0.4
j. Net Primary Productivity (g $C/m^2/yr$)	+1.3 to +14.4	+25.4 to +36.3

☆ The values in the 2030 column are the differences in the annual average of the parameter over the time period between the decade of 2025-2034 and the baseline period (1961-1990). The values in the 2090 column are the differences in the annual average of the parameter over the time period between the decade of 2090-2099 and the baseline period (1961-1990).

a. absolute change in degrees Celsius
b. absolute change in mm of precipitation
c. absolute change in mm of runoff per year
d. absolute change in cm of snowpack
e. change in the number of heat events (3 or more days that exceed or equal 38°C)
f. change in the absolute number of hot days at or over 38°C
g. change in the absolute number of cold days at or below 0°C
h. absolute change of growing degree days at the 7.2°C threshold
i. absolute change in g/m^2 of soil carbon
j. absolute change in $g/m^2/yr$ of NPP

Table 2-2: Seasonal Results: The range shows the deviations of the parameters from the seasonal averages of the baseline period (1961-1990) in the CCC and Hadley model scenario experiments.*

	2030☆				**2090**			
Parameter	**winter**	**spring**	**summer**	**fall**	**winter**	**spring**	**summer**	**fall**
a. Average temperature (°C)	+2.0 to +2.6	+1.5 to +2.6	+1.5 to +1.6	+1.6 to +2.0	+4.4 to +7.6	+2.9 to +6.4	+3.9 to +4.8	+3.5 to +5.4
b. Average precipitation (mm/season)	-12.8 to +13.24	+5.8 to +6.2	-14.0 to -6.9	-10.7 to -8.1	+31.1 to +39.9	+31.9 to +47.7	-30.9 to +15.7	+24.8 to +40.5
c. Runoff (mm/season)	-2.0 to +2.4	+25.2 to +32.4	-5.3 to +0.5	+0.5 to +1.5	+2.3 to +7.1	+32.2 to +41.1	-2.2 to +6.6	+9.6 to +10.2
d. Extreme rainfall events (> 5 cm/24 hrs)	-0.9 to -0.1	0 to +0.1	-0.1 to +0.2	-0.1 to +0.2	-0.5 to -0.1	+0.2	0 to +0.1	+0.3 to +0.4

☆ The results presented here are the differences between the seasonal average of the parameter over the time period between the decade of 2025-2034 and 2090-2099, and the baseline period (1961-1990).

* winter = December, January, February
spring = March, April, May
summer = June, July, August
fall = September, October, November
a. absolute change in degrees Celsius
b. absolute change in mm of precipitation
c. absolute change in mm of runoff over the season
d. change in the number of extreme rainfall events (exceeding 5 cm of precipitation in 24 hours)

Table 3-1: Average actual evapotranspiration (AET) values for the 30-year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

AET (mm/yr)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	401	437	410	466	440
Broadleaf	833	783	836	900	927
Mixed Forest	892	836	880	925	980
Savanna	566	575	593	576	612
Grasslands	378	380	398	414	425
Desert	317	353	322	321	349
Crop	568	557	590	623	642

AET (mm/yr)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	409	447	422	491	447
Mixed Forest	392	422	397	496	409
Savanna	783	758	819	896	872
Grasslands	350	354	367	381	393
Crop	545	536	573	606	620

Table 3-2: Average ratio of actual evapotranspiration (AET) to precipitation (PPT) for the 30-year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

AET/PPT (mm/yr)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	0.80	0.83	0.78	0.80	0.74
Broadleaf	0.84	0.86	0.84	0.82	0.78
Mixed Forest	0.83	0.84	0.83	0.81	0.77
Savanna	0.91	0.91	0.90	0.87	0.87
Grasslands	0.92	0.94	0.93	0.92	0.91
Desert	0.96	0.95	0.97	0.95	0.96
Crop	0.86	0.89	0.85	0.85	0.80

AET/PPT (mm/yr)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	0.71	0.75	0.68	0.72	0.63
Mixed Forest	0.71	0.76	0.66	0.76	0.59
Savanna	0.86	0.88	0.83	0.84	0.79
Grasslands	0.90	0.92	0.91	0.91	0.89
Crop	0.87	0.90	0.86	0.87	0.83

Table 3-3: Average net primary productivity (NPP) values for the 30 year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

NPP (g C/m^2/yr)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	222	256	241	306	282
Broadleaf	660	633	685	764	755
Mixed Forest	675	641	688	780	778
Savanna	220	229	233	219	241
Grasslands	113	116	123	126	135
Desert	98	111	97	90	109
Crop	339	326	358	356	382

NPP (g C/m^2/yr)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	227	271	253	335	298
Mixed Forest	170	180	166	249	214
Savanna	324	322	343	406	390
Grasslands	106	111	115	122	129
Crop	289	285	307	321	337

Table 3-4: Average soil carbon (SOIL C) values for the 30 year baseline period (1961-1990) and for the CCC and Hadley scenarios over the decades of 2025-2034 and 2099-2099.

SOIL C (g C/m^2)
Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	4692	4789	4780	4913	4931
Broadleaf	5654	5721	5694	5825	5740
Mixed Forest	5072	5193	5162	5282	5219
Savanna	2287	2319	2314	2367	2366
Grasslands	2033	2029	2023	2044	2027
Desert	2169	2172	2181	2217	2203
Crop	1843	1752	1767	1692	1722

SOIL C (g C/m^2)
Central Great Plains

	Baseline 1961-90	CCC 2030	Hadley 2030	CCC 2090	Hadley 2090
Conifer	4941	5066	5052	5215	5253
Mixed Forest	2228	2253	2271	2168	2249
Savanna	2815	2880	2884	2809	2830
Grasslands	2045	2042	2033	2048	2032
Crop	1760	1677	1682	1659	1658