CHAPTER 7

POTENTIAL CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE FOR THE GREAT PLAINS

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CHAPTER SUMMARY

Regional Context

The Great Plains produces much of the nation's grain, meat, and fiber, and in addition provides recreation, wildlife habitat, and water resources. Though more rural than the rest of the United States, the urban areas of the Great Plains provide housing and jobs for two-thirds of the people of the Great Plains. Soil organic matter is a major resource of the Great Plains as it provides improved soil water retention, soil fertility, and the long-term storage of carbon.

Climate of the Past Century

Over the 20th century, temperatures in the Northern and Central Great Plains have risen more than 2˚F (1˚C), with increases up to 5.5˚F (3˚C) in some areas. There is no evidence of a trend in the historical temperature record of the Southern Great Plains. Over the last 100 years, annual precipitation has decreased by 10% in the lee of the Rocky Mountains. Texas has seen significantly more high intensity rainfall.

Climate of the Coming Century

Air temperatures will likely continue to rise throughout the region, with the largest increases in the northern and western parts of the Plains. Seasonally, more warming is projected to occur in winter and spring than in summer and fall.

A pattern of decreasing precipitation appears likely in the lee of the Rocky Mountains while other sections of the Great Plains may experience slight increases. Although precipitation increases are projected for parts of the Great Plains, increased evaporation due to rising air temperatures are projected to surpass these increases, resulting in net soil moisture declines for large parts of the region.

Key Findings

- Productivity of crops and grasses of the region will likely respond positively to additional atmospheric carbon dioxide,especially those systems with adequate water and nitrogen such as alfalfa or soybeans.
- The warmer and predicted longer growing seasons will likely change the life cycles of all biological organisms and these changes will have profound impacts on the ecology of the Great Plains native ecosystems.
- The projected climate changes will likely alter the current biodiversity, resulting in a new composition of plant and animal species that may or may not be detrimental to society. A possible migration of invasive species across the Great Plains is a concern to stakeholders in the region because the rapid rate of change in climate may be disadvantageous to native species.
- Extreme temperatures and heat stress events, where the temperature remains over 90˚F (32˚C) for 3 consecutive days,will likely increase in the Southern Great Plains. These events will increase the heat stress on humans and livestock.
- Changes in the demand for irrigation water vary by crop type and the changes in the seasonality of precipitation. For example,in northeastern Colorado the consumptive demand for water for perennial crops such as grass and alfalfa was estimated to increase at least 50% over current use, however, consumptive water use for corn was not expected to increase substantially.
- Increased air temperatures may reduce soil organic matter affecting soil fertility, water-holding capacity, and the storage of carbon in the soil.
- The intensity of rainfall events may increase in the Southern Great Plains, resulting in more rainfall in shorter periods of time,with implications to urban and rural flood controls and soil erosion.
- Rural communities,already stressed by their declining populations and shrinking economic bases,are dependent on the competitive advantage of their agricultural products in domestic and foreign markets. A changing climate will likely bring additional stresses that will disproportionately impact family farmers and ranchers.
- Stakeholders in the region thought that community-based adaptive management was an important component for future planning.

POTENTIAL CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE ON THE GREAT PLAINS

PHYSICAL SETTING AND UNIQUE ATTRIBUTES

The Great Plains is often pictured as an agricultural landscape dotted with many small rural towns. In fact,the Great Plains is more rural than the rest of the US;nearly 40% of the region's counties have populations less than 2,500 people in contrast to the 20% of rural counties in the remainder of the US (Skold,1997;Gutmann,1999). These landscapes of grasses, forbs,and shrubs,interspersed with a variety of crops, give the Plains a sense of wide-open space. Increasing sizes and declining numbers of farms and ranches, fewer rural trade centers,and declining rural populations are recent socio-economic trends that further contribute to the remoteness of some rural counties. In contrast, other Great Plains'counties with large urban centers or with scenic amenities are experiencing population increases and economic growth (Drabenstott and Smith,1996).

Great Plains Vegetation Map

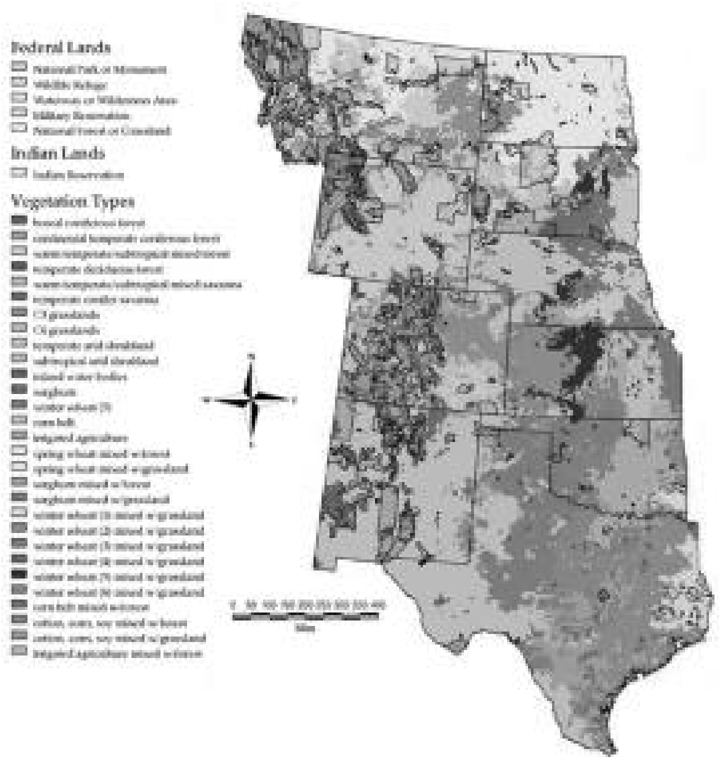

Figure 1. Distributions of the naturally occurring vegetation and the current planted agricultural crops are strongly linked to the gradients of temperature (north to south) and precipitation (west to east) within the Great Plains. Outlines show the federal land holdings in the region (vegetation map from Natural Resource Ecology Lab, Colorado State University. Potential natural vegetation according to VEMAP members, 1995). See Color Plate Appendix

Distributions of the naturally occurring vegetation and the planted agricultural crops (Figure 1) are strongly linked to the gradients of temperature (north to south) and precipitation (west to east) within the Great Plains (Figure 2). Cool-season grasslands in the North give way to warm-season grasslands in the central and southern parts of the region,which give way to drought-adapted shrubs in the southwestern parts and trees in the southeastern parts. As precipitation increases from west to east across the Great Plains,the native vegetation includes more mixed-grass and tall-grass species,and finally tree species. This precipitation gradient influences the use of irrigation in agriculture with a higher percentage of crops grown under irrigation in the western Great Plains and more crops dependent on growing season precipitation in the eastern Great Plains. The extreme western Great Plains is dominated by dryland cropping because of the reduced availability of water for irrigation. Crop types tend to follow the temperature gradient,with cool-season grains such as wheat,barley and oats dominating in the north and warm-season crops such as corn,sorghum,sugar beets,and cotton dominating in the south. However, the ability of the agricultural sector to expand across climatic zones is seen in that both corn and wheat can be found from North Dakota to Texas. Both natural and human systems cope with the natural variability in climate that characterizes the Great Plains. Periods of drought,a result of variability in climate,heighten the importance of water in this region.

Though dominated by grasslands,the Great Plains is also home to a diversity of plants and animals in shrublands, wetlands, woodlands,and forest communities. Riparian vegetation including deciduous forests, woodlands,and shrublands trace the Mississippi,Missouri,Platte,Kansas,Arkansas, Colorado,and Rio Grande Rivers. Juniper woodlands and conifer forests are found on the escarpments of the South Dakota badlands. Wind-deposited material forms extensive sand dune systems in

Great Plains Climate

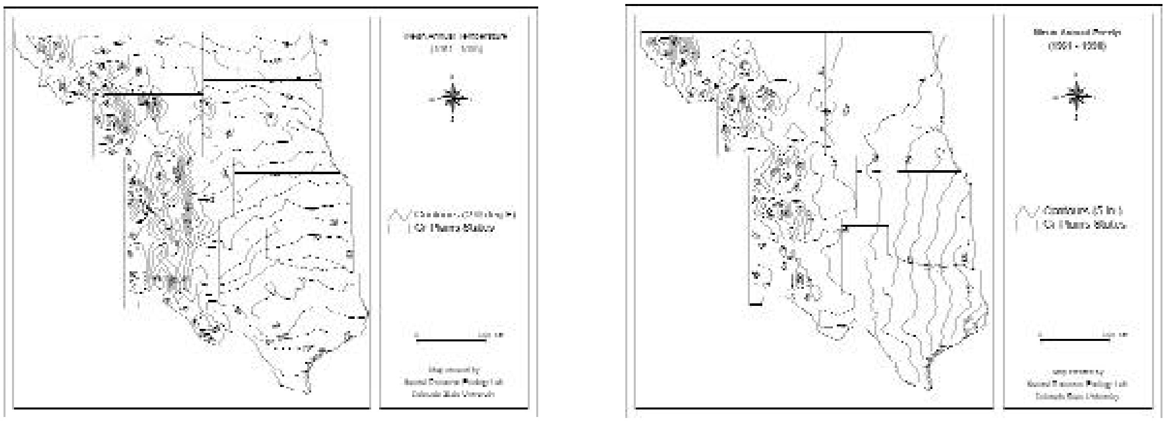

Figure 2. Great Plains climate is characterized by a strong north-south temperature gradient and a strong east-west precipitation gradient (averages based on the 1961-1990 period; data from Dennis Ojima, VEMAP climate). See Color Plate Appendix

the Great Plains. The Nebraska Sandhills contain the largest dune system covered by grassland in the United States (Ostlie et al.,1997). The rich grasslands of the region have been the basis of a large grazing system for thousands of years and currently support a diversity of cattle,bison,and other mammals,as well as a diversity of insect and bird species. Nearly 60% of the bird species that breed within the US are considered regular breeders within the Great Plains (Ostlie et al.,1997). Endemic plants and animals are found throughout unique habitats in the Great Plains. The wetland basins in the Prairie Pothole region of the Northern Great Plains and the playa lakes of the Central and Southern Great Plains are important habitat and breeding grounds for migratory waterfowl. Fish habitats include large streams with erratically variable flow, prairie ponds,marshes and small streams, and residual pools of highly intermittent streams. The largest and most diverse class of animals in the Great Plains is insects (Ostlie et al.,1997).

Throughout this region,soil organic matter is a major resource as it provides improved soil water retention,soil fertility, and the long-term storage of carbon. Soil organic matter integrates climate, geology, topography, and ecosystem dynamics (Jenny, 1980). The historical levels of grassland productivity and soil organic matter varied widely from north to south across the Great Plains, reflecting rainfall and temperature gradients (Jenny, 1980; Parton et al., 1987;Schimel et al.,1990; Peterson and Cole,1995). Ecosystem processes associated with productivity and decomposition influence the net changes in soil carbon (C) and these net changes serve as an index of soil fertility. Soil organic matter in grassland ecosystems is estimated to be an important reservoir of terrestrial carbon (Anderson,1991). For example,the average aboveground plant biomass production for a cool-season grassland in Havre,MT is 33.9 g m^{-2}. For a short-grass steppe ecosystem at the Central Plains Experimental Range in Colorado, aboveground plant biomass production is 45.9 g m^{-2} (Haas et al.,1957;Cole et al.,1990). Soil C values are 3230 and 2310 g m^{-2}, for Havre and the Central Plains Experimental Range, respectively. The conversion of Great Plains grasslands to croplands has resulted in major changes in soil organic matter and nutrient supplying capacity on these lands (Haas et al.,1957;Tiessen et al.,1982;Burke et al.,1990).

SOCIOECONOMIC CONTEXT

More than 70% of the Great Plains landscape (Figure 1) is used to produce a large proportion of the nation's food. Over 60% of the nation's wheat is produced in Montana,North Dakota,South Dakota, Nebraska,Kansas,Oklahoma,and Texas (Skold, 1997). The states of Texas,Oklahoma,New Mexico, Nebraska,Kansas,and Colorado produce 87% of the nation's grain sorghum. Over 54% of the nation's barley and 36% of the nation's cotton are produced in the region (Skold,1997). Livestock in the Great Plains constitutes over 60% of the nation's total, including both grazing and grain-fed cattle operations. Nearly 75% of the grain-fed cattle in the US are from the Great Plains,using the readily available supply of feed grains, over 50% of which is also produced in the region. Great Plains' farmers and ranchers have excelled by being adaptive and by incorporating new technologies to buffer their production against the highly variable climate. One tenth of Great Plains'cropland is irrigated. New

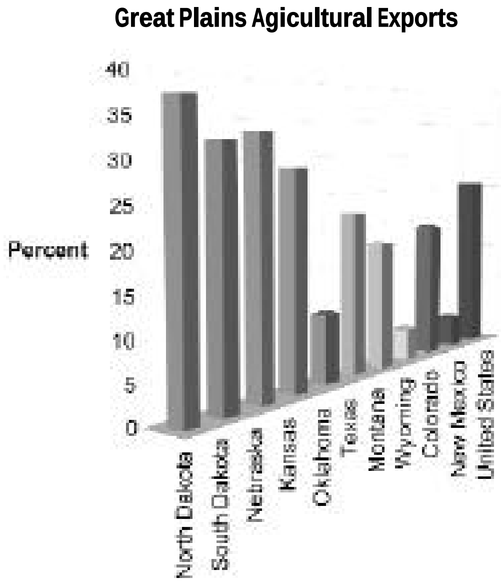

Figure 3. Agricultural exports are an important percentage of the total agricultural production within each state. (USDA, 1997 Census of Agriculture). See Color Plate Appendix

technologies in agriculture,crop genetics,and livestock production have facilitated the expansion and diversification of Great Plains agriculture.

However, Great Plains'communities are undergoing dramatic changes as the industries of agriculture, commerce,and finance consolidate (Drabenstott and Smith,1996;Barkema and Drabenstott,1996). When the Great Plains was being settled over 100 years ago,county seats were established about 30 miles apart in the eastern portion and somewhat farther apart in the central and western parts of the region (Drabenstott and Smith,1996). These county seats became the centers for government,commerce,and finance. Consolidation in agriculture, expansion of telecommunications,improved transportation,and discount retailing in rural areas are trends that have significantly reduced the number of viable rural economic centers (Drabenstott and Smith,1996),placing an increasing burden on rural governments to provide health care and education with dwindling financial resources. In contrast, those rural counties with large trade centers or scenic attractions,as in western Montana and Colorado, have seen growth in their local economies.

Agriculture,nationally and regionally, is becoming a farm-to-grocery integrated industry in response to consumer's demands for conveniently prepared and highly nutritious food products (Barkema and Drabenstott,1996). While the total area in farmland has remained fairly stable in the Great Plains, farms are getting bigger and the number of farmers fewer. Within the Central Great Plains,the total number of farms has gone from nearly 200,000 in 1930 to less than 100,000 in 1990 and big farms have increased from 10% to over 30% of the total number of farms (Gutmann,1999). More crops are grown under contracts with rigid production guidelines. Contract

Multiple Stresses on Urban and Natural Environments

The Rio Grande River is life itself to cities,industries,wildlife,and rare vegetation on both sides of the US-Mexico border. However, environmental stresses and socioeconomic changes are overwhelming the urban infrastructure in this area of the Southern Great Plains. The Rio Grande supplies water to the rapidly expanding human population as well as the rapidly expanding manufacturing facilities. Total population in cities along the US-Mexico border is projected to double in less than 30 years. More than 60% of all US-Mexico trade passes through Laredo, Texas in trucks,making it the largest land port in the US. Mexico will soon displace Japan as the number two trading partner of the US,despite the fact that Mexico's economy is one-twelfth the size of Japan's.

The rapid increase in trade flowing through border cities, following passage of the North American Free Trade Agreement (NAFTA),has resulted in a complex array of costs and benefits to border cities. Industrial point source pollution as well as automobile emissions are a significant problem in the industrialized areas of the Lower Rio Grande Valley and Northern Mexico. In the unincorporated shanty-towns along both sides of the Rio Grande border, infrastructure for water supply and wastewater treatment is generally absent or totally inadequate. Reported cases of hepatitis and other viral diseases are typically two times greater in border counties compared to the statewide average.

The state of human health and environmental quality are very closely tied to land use, climate variability, air quality, and water supply. Climate change is likely to exacerbate these multiple stresses on human and natural systems;both by changes to local weather and to the flow regime of the river.

production varies across crop types,but even the small proportion of contracted wheat and feed grain is rising. Cattle feeders without contracts report that their markets have shrunk (Barkema and Drabenstott,1996).

One consequence of changing agricultural economics is that larger farms' volume of business often justifies searching greater distances to seek lower prices on purchased items or higher prices on items sold (Barkema and Drabenstott,1996). Local markets decline as the large rural centers or urban areas attract consumers.

Great Plains' agriculture has also been limited by two other global trends. First,the largest increase in the agricultural market is in food products that are ready or nearly ready for human consumption,such as cereals and snack foods,meats,fruits,and vegetables. The main agricultural crops of the Great Plains are bulk commodities such as wheat and corn. With the exception of meat processing,minimal food processing is done within the Great Plains because of prohibitive transportation costs to reach the major markets. Secondly, the international markets for US agricultural production have shifted from the grain purchases of the Soviet Union and the European Union to the more diversified markets of Asia. In 1996, over 40% of US agricultural exports went to Asian markets (Barkema and Drabenstott,1996). From 4 to 38% of each Great Plains state's crop production — grain and livestock — is exported outside of the US (Figure 3). Thus,Great Plains agriculture is highly sensitive to changing consumer preferences and the global economy.

Although agriculture dominates land use in the Great Plains,the percent share of agriculture is small,2% of the 1997 gross state product of all Great Plains states (US Department of Commerce 1998). The Northern Great Plains states are more dependent on agriculture than the Central Great Plains states,which are more dependent on agriculture than the Southern Great Plains states (Figure 4). Agriculture, forestry, and fisheries comprise 11% of North Dakota's gross state product,in contrast to 1% in Texas. In 1996,North Dakota,South Dakota,and Nebraska ranked one,two,and three nationally in terms of the farm share of the gross state product.

Changes in agricultural economies and lifestyles in the Great Plains are altering demographic patterns of the region. Populations are declining in most rural areas. In North Dakota, over 65% of the counties have fewer than 6 residents per square mile. The average age of a farm operator in the Central

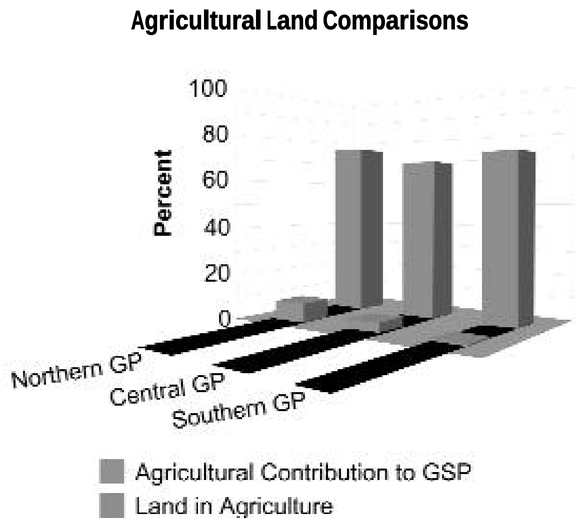

Figure 4. The Northern Great Plains are more dependent on agriculture than the Central which is more dependent on agriculture than the Southern Great Plains, yet agriculture dominates land use in all regions of the Great Plains. (Economic data from US Dept of Commerce, Bureau of Economic Analysis, Regional Economic Analysis Division, June 1998, and land use data from USDA, 1997 Census of Agriculture.) See Color Plate Appendix

Great Plains is nearly 54 years,52 years in the Northern Great Plains,and over 56 years in the Southern Great Plains (USDA Census of Agriculture, 1997). Urban population in the Central Great Plains has gone from 27% of the total population in 1930 to 67% in 1990 (Gutmann,1999). Some 80% of the people in Texas live in cities. This shift in population increases the demand for services in the urban areas and introduces urban problems such as deteriorating air quality. In addition, agricultural to municipal water transfers are becoming increasingly common as more water is needed for urban inhabitants (NRC,1992).

ECOLOGICAL CONTEXT

Water and temperature strongly influence the structure and function of the Great Plains grasslands. The transition from short-grass steppe in the lee of the Rocky Mountains to mixed prairie and finally tallgrass prairie at the eastern edge of the Great Plains corresponds to a precipitation gradient of low rainfall east of the Rockies to relatively high and more evenly-distributed rainfall in eastern parts of the region. The temperature gradient from north to south in the Great Plains represents another important gradient that determines plant type distribution and local abundance (e.g., warm-season versus cool-season grasses).

Organic matter in Great Plains'soils also varies with temperature and precipitation gradients (Jenny, 1980; Parton et al.,1987;Schimel et al.,1990; Peterson and Cole,1995). The net changes in soil C integrate ecosystem processes associated with productivity and decomposition rates that change with weather and with land management. Changes in soil organic matter serve as an index of soil fertility. Soil carbon storage is the largest carbon pool in the grassland ecosystems. Soil carbon storage and fluxes are influenced by vegetation, characteristic soil properties,inherent climate regime,and land use practices. The current carbon level is not only determined by the current state of these factors but is also dependent on the land use history. Changes in rates of decomposition,plant production,and respiration from climate and land management affect the storage and flux of carbon from the soil. Rainfall amounts tend to control the amount of plant production that occurs whereas temperature determines decomposition rates. However, both rainfall and temperature interact in both processes to a certain degree. Changes in soil carbon are responsive to agricultural practices that alter the amount of plant material entering the soil. Changes in tillage practices, grazing patterns,and manure distribution all affect the storage of soil carbon. Conversion of grasslands or forests to cropland can result in a rapid decline in carbon stores. Up to 50% of the soil carbon and the woody biomass of the forest can be lost due to cropland conversion (Haas et al.,1957;Cole et al.,1989,1990). Ecosystems are often sensitive to changes in extreme events. Changes in low or high temperature extremes or in drought occurrence can rapidly change the structure of an ecosystem,especially when these modifications in extremes coincide with a disturbance event,such as fire,that resets the ecosystem to a different vegetation composition. In these instances,large fluxes of carbon and long-term changes in carbon storage may result.

Three environmental parameters of global change — increased carbon dioxide,increased temperature,and altered precipitation — will likely affect Great Plains ecosystems primarily through their combined effects on plant and soil water interactions,photosynthesis,and other aspects of plant metabolism. Responses will result from direct effects of the changing environment on individual plants (e.g.,productivity),as well as from changes in the mix of plant communities and cropping systems that occur due to different sensitivities of individual species. In order to assess these changes at the regional scale,the ecosystem model CENTURY (Parton et al.,1987,1994) was used to simulate plant productivity and carbon storage in natural and in agricultural ecosystems.

Both of the two climate scenarios used in this assessment have a marked increase in temperatures, with the Canadian scenario being the warmer of the two scenarios (see Climate chapter). Both scenarios are associated with increases in precipitation,however, the regional pattern and the magnitude of the increase in precipitation is highly varied. Of the two,the Hadley scenario simulates a slightly wetter growing season compared to the Canadian scenario. The timing of precipitation,seasonal changes in temperature,and the increased atmospheric carbon dioxide concentrations determine the impact of the two climate scenarios on the plant productivity and soil carbon levels of the Great Plains.

In order to capture the impact of land use practices on carbon storage and fluxes,the dominant natural or managed vegetation type was assigned to individual grid cells across the region. The CENTURY model simulated net carbon storage in these grid cells for each climate scenario. These simulations were based on current dominant agricultural practices and do not represent adaptive agricultural management practices being tested for maximum carbon storage. Recent no-till or reduced-till practices have been developed to lessen the impact on the soil carbon losses from croplands. The use of adaptive cropping management strategies in the US is estimated to account for 0.08-0.2 PgC/y (Lal et al., 1998),although these cropland areas are vulnerable to large carbon losses due to removal of vegetation and soil disturbances on an annual basis. The historical land management usage greatly determines the current carbon storage and potential fluxes from these managed systems.

For both climate scenarios,the increased atmospheric carbon dioxide associated with the climate changes partially ameliorates the negative warming trends on crop and grassland productivity (Figure 5). Productivity of most crops and grasses responds positively to additional carbon dioxide,especially those with adequate nitrogen such as the nitrogen-fixing alfalfa or soybean systems. These cropping systems,when simulated under dryland management,perform much better with increased carbon dioxide since these cropping systems are able to use the available soil moisture more effectively than under conditions in the absence of elevated carbon dioxide.

Soil organic matter responds to changes in vegetation as well as atmospheric carbon dioxide levels

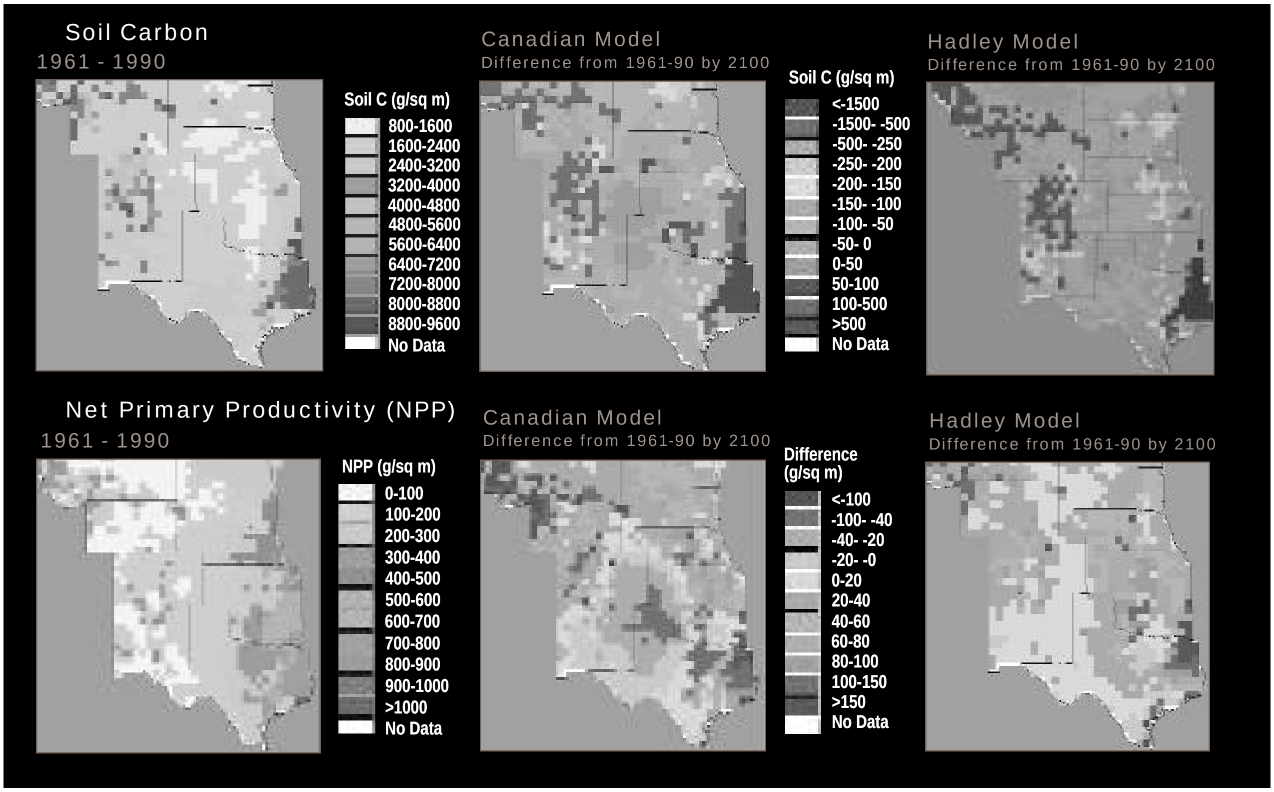

Figure 5. The productivity of the Great Plains increases from west to east and from north to south, following the precipitation and the temperature gradients. Land uses are strongly influenced by productivity. Both climate scenarios increase the moisture stress on the central parts of the Great Plains and productivity declines in this region. Soil organic matter in the Great Plains is an important reservoir of terrestrial carbon. The amount of carbon stored in the soil is strongly influenced by past and present land management practices and weather patterns. Where moisture levels and productivity decline, soil carbon may actually increase as decomposition processes become limiting. Where soil moisture levels increase from increased water use efficiency, soil carbon levels may decline. (CENTURYresults from VEMAP analysis, Natural Resource Ecology Lab, Colorado State University.) – See Color Plate Appendix

(Figure 5). Where moisture levels and productivity decline,soil carbon may actually increase as decomposition processes become limiting as seen along the lee of the Rocky Mountains and especially in the Southern Great Plains. The southeastern parts of the Great Plains lose soil organic matter due to the increased soil moisture levels resulting from increased water use efficiency associated with the elevated carbon dioxide levels. In the dryland systems with little excess crop residue,soil organic matter continually declines over the duration of the climate change scenario. Systems such as wheat-fallow continue to mine soil carbon as temperature and moisture conditions facilitate release of carbon by microorganisms during the fallow period. In systems where excess crop residue is available and incorporated into the soil system,there tends to be a build up of soil carbon. This is especially evident in the productive irrigated soybean/corn rotations where nitrogen fixation by the beans and the additional residue input from corn rapidly builds soil carbon.

Some changes, such as enhanced forage production in response to elevated carbon dioxide,may be beneficial. However, plant growth under elevated carbon dioxide conditions directly influences important metabolic responses that bear on forage quality, including reduced crude protein content and increased total non-structural carbohydrates. This direct effect on forage quality may be overshadowed by quality changes due to altered plant communities,such as changes in the balance of dominant warm- and cool-season grasses,more legumes,or more shrubs. The warmer and predicted longer growing seasons will likely alter life cycles of all biological organisms and these changes will likely have profound impacts on the ecology of the Great Plains native ecosystems.

CLIMATE VARIABILITY AND CHANGE

The Great Plains climate is characterized by a strong north-south temperature gradient and a strong east-west precipitation gradient (Figure 2). Annual precipitation ranges from less than 7.8 inches (200 mm) on the western edge to over 43 inches (1,100 mm) on the eastern edge of the Great Plains. Average annual temperature is less than 39˚F (4˚C) in the Northern Great Plains and exceeds 72˚F (22˚C) in the Southern Great Plains.

The spring and summer peaks in precipitation provide growing season moisture for the prairies. For example,75% of the annual precipitation falls during the growing season at the Konza Prairie,Kansas (Hayden,1998). Growing seasons range from 110 days in the Northern Great Plains to 300 days in the Southern Great Plains (Donofrio and Ojima,1997). Monthly average maximum temperatures exceed 91˚F (33˚C) in most places on the Great Plains during one of the summer months. Three consecutive days of temperature over 90˚F (32˚C) can signal heat stress for both humans and livestock.

The variability of weather in the Great Plains is a characterizing feature,as “normal” years are rare and extremes are most often the common experience. Blizzards, floods,droughts,tornadoes,hail storms, thunderstorms,high winds,severe cold,and extreme heat often arrive suddenly, disrupt normal daily activities,and can be life-threatening.

Analysis of weather data for the last 100 years in the Great Plains indicates a warming pattern in the Northern and Central Great Plains,but no evidence of a trend in the historical temperature record for the Southern Great Plains (see Climate Chapter). Temperatures have risen in the Northern and Central Great Plains by about 2˚F (1˚C) in the 20th century (Karl et al.,1999),with increases of 5˚F (3˚C) in Montana,North Dakota,and South Dakota. This warming trend in the Northern Great Plains is reflected in 6 fewer days with temperatures less than 32˚F (0˚C). Meteorologists use indices,such as heating degree days and cooling degree days,to describe likely changes that would be required to maintain the human quality of life — additional heating needed in the winter or cooling in the summer. Heating Degree Days (HDD) are the degrees the average daily temperature is below 65˚F (18˚C). Cooling Degree Days (CDD) are the degrees the average daily temperature is above 65˚F (18˚C). The Northern Great Plains has had significantly fewer heating degree days (-628 HDD) and significantly more cooling degree days (40 CDD) over the 20th

Temperature Change - 20th & 21st Centuries

See Color Plate Appendix

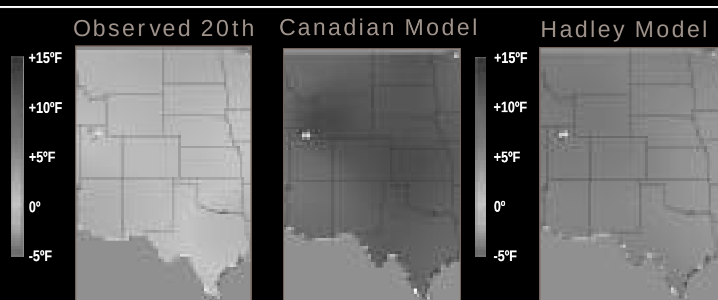

Figure 6. The observed changes in air temperature for the Great Plains over the last century indicates a greater warming in the north than in the south on average.

The model scenarios indicate an additional 5˚F (Hadley scenario) to 12˚F (Canadian scenario) increases over the next century for much of the Plains (data this assessment).

Precipitation Change - 20th & 21st Centuries

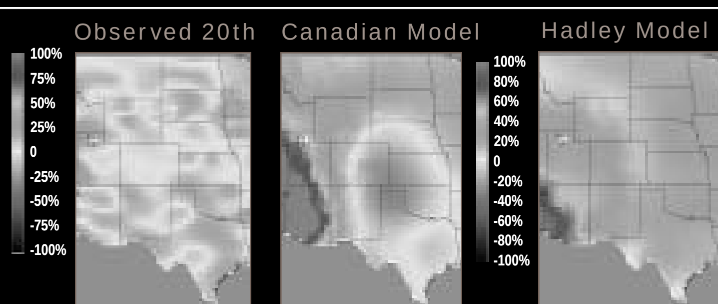

Figure 7. Precipitation averages over the last century indicate a decrease in precipitation to the east of the Rockies. Several areas, most notably Texas, have precipitation increases (data this assessment).

The Canadian model projects decreases in precipitation in the southern Plains and increases in the north. The Hadley model projects increases over almost the entire region, but some decreases are also evident east of the Rockies.

century (Chapter 1). Daily minimum temperatures throughout the year have increased more than maximum temperatures, indicating greater nighttime warming. In the Northern Great Plains, over the last 50 years the mean date of the last measurable snow (greater than 1 inch on the ground) has occurred 4 days earlier. This significant change indicates a warming trend in the winter-spring months.
Over the last 100 years, annual precipitation has decreased by 10% in eastern Montana, eastern Wyoming, western and central North Dakota, and Colorado and has increased by 5 to 20% in South Dakota, Oklahoma, Texas, and parts of Kansas (Karl et al., 1999). Texas has seen an increase in high intensity precipitation events, with significantly more area reported in severe wetness and significantly less area reported in drought conditions over the last 100 years (see Chapter 1).

The two climate scenarios used in this Assessment (see descriptions in Climate Chapter) project a continuation of the trends seen in Great Plains historical climate: higher temperatures, and for some areas, greater precipitation. The Canadian scenario projects greater increases in temperature than the Hadley scenario (Figure 6). In both scenarios, the annual average temperature rises more than 5˚F (3˚C) by the 2090s. Increases in temperature are greatest along the eastern edge of the Rocky Mountains. Minimum temperatures rise more in the winter (December-January-February) than the summer (June-July-August). By the 2090s winter temperatures increase 14˚F (7˚C) compared to 9˚F (5˚C) for summer in the Canadian scenario, and 9˚F (5˚C) versus 7˚F (4˚C) for the Hadley scenario.

Great Plains' annual precipitation increases by at least 13% in both scenarios by the 2090s (Figure 7). A pattern of decreasing precipitation trends appears in the lee of the Rocky Mountains and is greatly accentuated in the Canadian scenario. The annual increases are greatest in the eastern and northern parts of the Great Plains. Winter precipitation increases slightly more than summer precipitation in both scenarios. Precipitation is likely to occur in more intense rainfall events, especially in the Southern Great Plains. Although precipitation increases are projected for parts of the Great Plains, increased evaporation from rising air temperatures will outweigh the surplus of moisture from increased precipitation and soil moisture will likely decline for large parts of the region.

Drought conditions within 8 climate divisions in the Great Plains have been described using the Palmer Drought Severity Index (PDSI): values between 1.99 and –1.99 are considered near normal. Values of –2 to –2.99 are considered moderate drought; values of –3 to –3.99, severe drought, and values less then –4 are considered extreme drought. The droughts of the 1930s and 1950s are shown as years or periods where the PDSI was less then –2 and both climate scenarios suggest future periods where drought conditions appear likely (Figure 8). If vegetation cover is not maintained in the sand dune areas of the Great Plains, there is some chance that increased droughtiness may result in mobilizing sand dunes (Muhs and Maat, 1993).

The number of times that a climate division in each of 8 Great Plains states experiences three consecutive days exceeding 90˚F (32˚C) also increases in

Annual Average Palmer Drought Severity Index (PDSI)

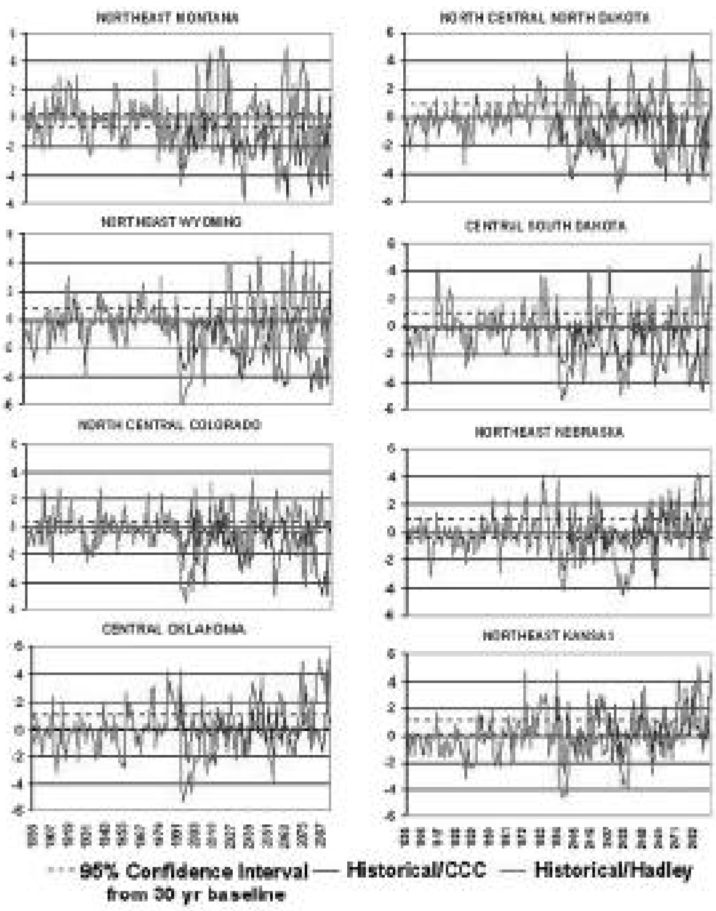

Figure 8. The droughts of the 1930s and 1950s are shown as years or periods where the Palmer Drought Severity Index (PDSI) was less then –2 and both climate scenarios (CCC = Canadian, Hadley) suggest future periods in each of these 8 climate divisions in the Great Plains where drought conditions appear likely. The 95% confidence interval for the historical period of 1960 to 1990 is shown as two dashed lines (VEMAP data, Natural Resource Ecology Lab, Colorado State University.) See Color Plate Appendix

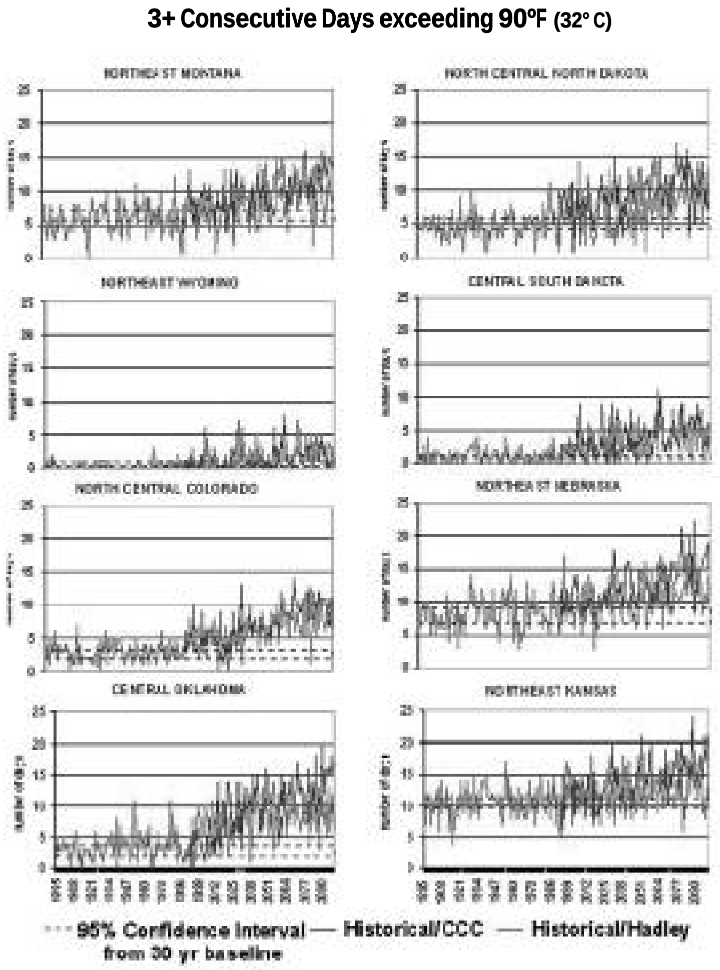

Figure 9. Heat stress events can be triggered for livestock and for humans when the temperature exceeds 90˚F (32˚C) for three or more consecutive days. The number of times that a climate division in each of the 8 Great Plains states experiences three consecutive days where temperatures exceed 90˚F (32˚C) increases in both scenarios. The 95% confidence interval for the historic period of 1960 to 1990 is shown as two dashed lines (VEMAP data, Natural Resource Ecology Lab, Colorado State University). See Color Plate Appendix

both scenarios (Figure 9). For the climate divisions in Colorado and Oklahoma, this represents more than a doubling of the number of times such heat stress would occur.

KEY ISSUES

Workshops held in the Great Plains identified stakeholders' concerns about climate change and climate variability in the context of other current stresses on the environment and society (Ojima et al., 1997; Seielstad, 1998; National Aeronautics and Space Administration and University of Texas at El Paso, 1998). The key issues explored in detail below apply equally to the Northern, Central, and Southern Great Plains. Additional issues were identified and these are discussed as a group following the sections below. The key issues impact the full spectrum of industries and ecosystems in the Great Plains and were chosen partly because they are common to a great deal of the economy and ecology of the region; for example, all of the key issues relate to agriculture.

- Changes in the timing and quantity of water could exacerbate the current conflicts surrounding water allocation and use in the Great Plains.
- Potential shifts in climate variability may increase the risks associated with farming, ranching, and wildland management.
- Invasive species may have unanticipated indirect impacts on the Great Plains ecology and economy.
- Rural communities, already stressed by their declining populations and shrinking economic base, are dependent on the competitive advantage of their agricultural products in domestic and foreign markets. A changing climate will bring additional stresses that will disproportionately impact family farmers and ranchers.
- Soil organic matter is a critical resource of the Great Plains as it provides improved soil water retention, soil fertility, and the long-term storage of carbon. (see Agriculture Solutions box)

1. Changes in Timing and Quantity of Water

Current Issues

Water supply and demand, allocation and storage, and quality are all climate-sensitive issues affecting the region's economy. Competing uses for water include agriculture, domestic and commercial uses, recreation, natural ecosystems, and industrial uses including energy and mining. Texas leads the Great Plains states in the total amount of water withdrawn from either surface or groundwater sources (Figure 10) although Wyoming has the highest per capita use of water, the result of a small human population and a large agricultural use. Agriculture (irrigation and livestock) withdraws the largest share of water in every Great Plains state, except North Dakota (Figure 10). "Consumptive use" refers to that part of water withdrawn that is evaporated, transpired, incorporated into products and crops, consumed by humans or livestock, or otherwise removed from the immediate water supply (Solley, 1997). Agriculture is the largest consumptive use category in every state (Figure 10), accounting for over 40% of the total water used in most states.

Sources of water include precipitation,surface water in rivers,streams and lakes,and groundwater in aquifers. Surface water supplies most of the water withdrawals in Montana,North Dakota,and Wyoming whereas groundwater sources are greatest for Nebraska (Solley, 1997). Seasonality of precipitation also influences user dependency on these sources (Miller, 1997). Irrigated agriculture along the eastern edge of the Rocky Mountains is more dependent upon snowmelt runoff from the Rocky Mountains than on spring and early summer rains. Non-irrigated agriculture in the eastern parts of the Great Plains is less dependent upon snowmelt runoff and more dependent upon the spring and early summer rains.

Water quality is a current constraining factor in the productive use of water. The management of water quality problems,such as salinity, nutrient loading, turbidity, and siltation of streams,is tied to the availability of water to accommodate agricultural and human demands. Dams,diversions, channelizations, and groundwater pumping have influenced nearly all freshwater ecosystems in the Great Plains by altering riparian habitats,aquatic ecosystems, hydrological cycles,and recreational opportunities.

In each state of the region,the allocation of water among competing 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. For example,laws restrict transfers from agricultural to non-agricultural uses in some states such as Nebraska. Water apportionment decision-making among the various sectors is a major challenge and is currently marked by conflict,negotiation,or cooperation,depending on the setting. While interstate allocation issues have generated significant conflict,there are promising signs of cooperation in the tri-state effort between Colorado,Wyoming,and Nebraska to address endangered species preservation on the Platte River. In addition,negotiations between urban centers and irrigators who are willing to sell their water rights or rent water owned by the city are becoming commonplace in some states. Management of both surface water and groundwater to meet diverse and increasing water needs is a major political and management concern in the region.

Potential Impacts

The projected increases in temperature and droughts are expected to exacerbate the current competition for water among the agricultural sector, urban and industrial users, recreational users,and natural ecosystems,as well as within each user community. As water needs and available resources differ across use categories and within categories, changes such as a shift in the seasonality of precipitation will impact users differently. For example, alteration in the timing of snowmelt runoff from the Rocky Mountains would impact the current system of water management in the Platte Basin. In the South Platte Basin, water is taken from the streams/rivers in the spring and pumped strategically into nearby shallow groundwater aquifers such that the release of the recharge meets downstream user needs at the appropriate time. Winter warming coupled with an increase in winter precipitation could result in earlier and greater snowmelt from the Rocky Mountains. This storage system along the South Platte is adapted to the current climate and temporal needs of water users;under projected changes,the release of recharge may not meet the timing or amount of the downstream users' water needs.

Great Plains Water Use

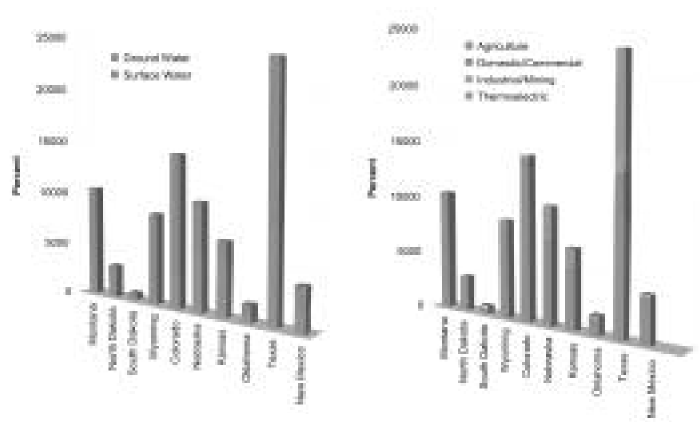

Figure 10. Surface waters are important sources for the western and northern Great Plains. Ground water, such as the Ogalalla aquifer, supplies large shares of the water for Nebraska, Kansas, and Oklahoma. Although the total amount of water withdrawal varies across the Great Plains, agriculture is the dominant consumptive use in all states (Solley, 1997). See Color Plate Appendix

Irrigated cropland has allowed for a diversification in agriculture in the Great Plains. Lack of soil moisture can greatly reduce yield of crops and forage. Ojima et al.(1999) found that,under the Canadian climate scenario,consumptive demand for water for perennial crops such as grass and alfalfa would increase at least 50% by the 2090s over current use (average of 1981-90). However, because growing season precipitation increases,consumptive water

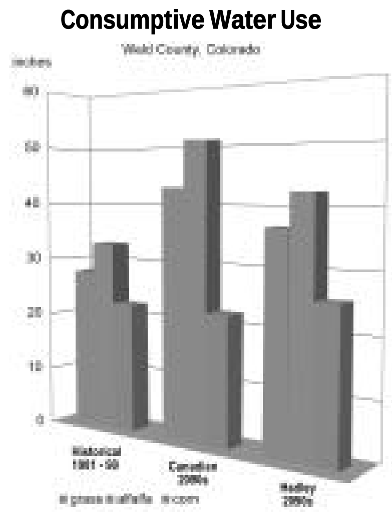

Figure 11. Lack of soil moisture can greatly reduce yield of crops and forage. Under both climate scenarios, the consumptive demand for water on grass pasture increases more than 50% while the water needs for irrigated corn change little. Perennial crops experience an increase in consumptive demand for water; the size of the increase depends on the climate scenario (Ojima et al., 1999). See Color Plate Appendix

use for corn does not increase substantially (Figure 11). Thus,depending upon the future changes in temperature and precipitation,both irrigated lands and farmed acreage not currently irrigated could compete for scarce water resources in the future.

Potential increases in drought and/or storm intensity could severely impact water quality. 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. Many small towns in the Great Plains struggle to meet current drinking water standards. The projected increase in intense rainfall in the Southern Plains may increase problems with runoff in urban areas or runoff of livestock wastes from feedlots.

Adaptation Options

There are existing strategies that deal with droughts, chronic water shortages, extreme weather events and year-to-year climate variability.These strategies favor improvement and maintenance of soil, water, biotic,and land resources. Numerous cultural,economic,political,and social factors often inhibit a rapid and widespread adoption of more sustainable practices (Wilhite,1997). These existing practices and new technologies are possibly only marginal in effecting the climate change impacts.

Water availability in both dryland and irrigated systems could be improved by existing and new technologies for residue management and tillage practices. Various techniques have been used to increase storage and availability of water:management of groundwater aquifers;enhanced snowpack storage in mountains through forest management; crop management practices that enhance soil moisture retention through crop stubble,wind breaks, and mulches;and snow management strategies on the Plains. Such techniques could increase the quantity of stored water to provide resilience to a changing climate. Irrigation scheduling,adjusting yield target to match available water, and/or changing cropping systems or land use in the event that irrigation costs exceed the worth of increased production are other options. More efficient irrigation application methods in agriculture (such as precision farming) could decrease water consumption. The need for better, non-consumptive water use in urban areas could be achieved through conservation, xeriscaping (low water-use landscaping),and the use of gray water systems for landscapes. However, the effectiveness of such measures and distribution of impacts across various water users would depend on a number of both natural and institutional factors. For example, more efficient non-consumptive water use in one location does not necessarily result in less overall water demand as diminished use at one point may simply allow increased use downstream. In addition,potential water quality issues may arise with repeated use.

Water trading is another drought management response that is more developed in some states than in others. In Colorado, for example,there are active water rental markets along the Front Range of the Rocky Mountains,and many cities that have acquired water rights in advance of need routinely rent them back to agricultural users in normal water years. This practice provides a drought buffer for the urban uses because the city can decide not to lease the water during drought years. “Water banking”is a term applied either to conjunctive use of groundwater and surface water supplies or to a formal mechanism to facilitate voluntary water transfers. This is a relatively new concept in the Great Plains region,but both Texas and Kansas have instituted programs to encourage water banking.

2. Weather Extremes

Current Issues

Extreme weather events include severe winter snow storms,ice storms,high winds,hail,tornadoes,lightning,drought,intense heavy rain, floods, heat waves, extreme cold snaps,and unexpected frosts. Natural systems have adapted to this variability, but climate extremes have significant economic impacts on farmers and ranchers as well as the human communities in the Great Plains. For example,in May of 1999,an outbreak of F4-F5 tornadoes hit the states of Oklahoma,Texas,Kansas,and Tennessee, resulting in at least $1 billion in damages and 54 deaths. In fall 1998,severe flooding in southeast Texas from 2 heavy rain events with 10-20 inch rainfall totals caused approximately $1 billion in damages and 31 deaths. The severe drought from fall 1995 through summer 1996 in the agricultural regions of the Southern Great Plains resulted in about $5 billion in damages.

Urban and industrial infrastructures have also been impacted by extreme weather events. For example, the summer 1998 heat wave and drought severely impacted roads and pipelines in Texas. In addition, this extreme event resulted in over $6 billion in damages from Texas/Oklahoma eastward to the Carolinas and at least 200 deaths. The April 1997 flood put nearly 90% of Grand Forks,North Dakota under water and caused over $1 billion in damages.

The extremes of hot and cold,as well as wet and dry, pose challenges for livestock enterprises. In the winter of 1996-97,eight blizzards in North Dakota resulted in the deaths of over 120,000 cattle,9,500 sheep,and several thousand hogs and poultry (Junkert,personal communication via Seielstad) with direct losses of $250 million. Heat,particularly hot-humid conditions,impacts the performance of intensive livestock operations more than cold,and cattle are impacted to a greater degree than sheep (Hahn and Morgan,1999). In August 1992,a 3-day heat wave after a relatively cool period in central and eastern Nebraska caused several hundred feedlot cattle deaths. In a July 1995 heat wave, over 4,000 feedlot cattle died in the central US (Hahn and Morgan,1999). Weather is the primary factor in management decisions on the timing of calving seasons because newborns and neonatal animals are vulnerable to extremes of both heat and cold.

Potential Impacts

Analyses of the historical record (1895-1995) identify increases in high intensity rainfall events (greater than 2 inches/day) in the Southern Great Plains (Karl et al.,1999). Model results suggest that the frequency of high intensity rainfall will continue to increase in the Southern Great Plains, resulting in more rainfall in shorter periods of time. The historical record also indicates that 7-day extreme precipitation totals are increasing in the Great Plains (Kunkel et al.,1999). In both the Canadian and the Hadley scenarios,the frequency of very high temperatures and heat stress events appear likely to increase.

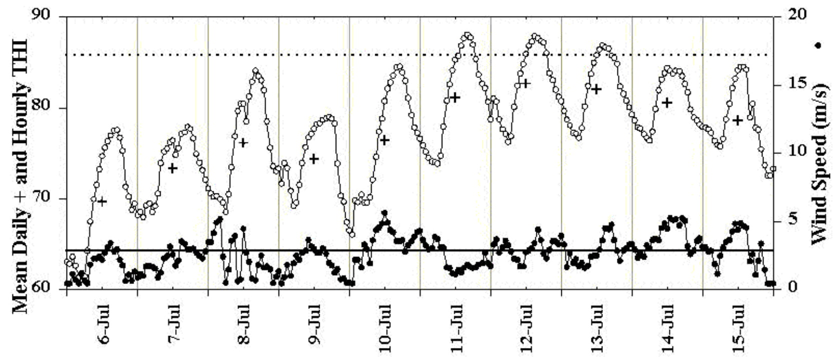

Figure 12. The hourly temperature-humidity index (THI) values and windspeeds at a mid-central US location in the highest-risk area of an early summer, 1995 heatwave which caused large-scale livestock deaths and performance losses (Hahn and Mader, 1997). The temperature-humidity index averaged above 80 for more than 3 days here, and nighttime relief (THI less than 74) from the extreme daytime heat did not occur naturally. ***See Color Plate Appendix***

Stakeholders in the region view slow changes in climate averages as less of an issue than the possibility of greater or more frequent extremes. Hail suppression programs, rainfall enhancement programs,and drought mitigation programs currently operate in different areas in the Plains. These current concerns about extreme events were also highlighted as concerns under a changing climate in the Great Plains.

Adaptation Options

Stakeholder groups recognized that climate in the Great Plains is inherently variable,and that decisions regarding land use,land management,and development are made with this variability in mind. This variability underscores the need for adaptation strategies that reduce risk and uncertainty through better access to more timely, accurate,easily accessible information about near-term weather (weeks to growing season), extreme weather events,and forecasts for weather 6 to 18 months in the future. Physically, emotionally, and psychologically, people cope better with a disaster or an abrupt change if they are prepared or if a response plan is in place.

Making decisions under uncertainty requires that strategic (long-term) planning decisions be made so that a tactical (short-term) response can be initiated when needed. For example,the stress of a heat event can be minimized if livestock operators have 3-4 days to reduce feed intake (and therefore,metabolic heat production) in cattle. Livestock can cope with high heat during the day if nighttime temperatures are sufficiently low for the animals to cool down. In the 1995 event,the heat wave was sufficiently extreme (Figure 12) and extensive to cause heat loads which exceeded the stress threshold and led to impaired performance for many animals and death for those most vulnerable (Hahn and Morgan, 1999). If livestock operators knew that the heat index was going to exceed a certain threshold more often,operators could make strategic decisions to prepare for extreme heat events through some type of cooling management,such as fans,shade,or the use of water sprays. Without such forethought,an immediate response to cool animals is difficult to arrange. Information about climate and real-time weather would allow farmers and ranchers to make strategic decisions and be able to respond quickly when necessary.

In the Northern Great Plains,the stakeholders discussed how they could build learning communities in which stakeholders share information with each other;in other words,information flows in all directions (Seielstad 1998). Information outreach could include short television segments containing information pieces on climate and other aspects of the environment,a web site with interactive information,newsletters,and partnerships with the National Park Service to develop information kiosks about environmental changes.

Nearly all Great Plains states have drought management plans in place or are developing them. These plans tend to be reactive, focusing on the emergency response to drought rather than a mitigation plan (Wilhite,1997). Such plans may need to be updated to reflect the changing demographic and economic conditions within Great Plains states. Colorado’s drought plan incorporates a monitoring system,an impact assessment,and a response system. The monitoring system allows for the early detection of a drought. In the assessment plan,the potential impact of a drought on 8 sectors is evaluated: municipal water, wildfire protection, agricultural industry, tourism,wildlife,economics,energy loss, and health. The response phase deals with the unmet needs identified by the assessment and assists local communities when their capabilities are exceeded. In the aftermath of a drought,an evaluation of the response provides suggestions to revise and improve the drought response system. The impact of a drought—economic,social or environmental—is the combination of the meteorological event and the vulnerability of the human community (Wilhite,1997). If increasing demand for water in the Great Plains increases the social vulnerability to water supply disruptions,then the impact of future droughts will be greater even if climate patterns were to remain the same. Thus,policies that develop regionally appropriate drought mitigation measures today will likely reduce the social impacts associated with future droughts,whether or not they are the result of climate change (Wilhite, 1997).

3. Invasive Species and Biodiversity

Current Issues

Natural systems in the Great Plains are currently stressed by a variety of agents including fragmentation of grasslands through land conversions to agriculture,cities,and roads;sedimentation and water pollution from fertilizer and pesticide runoff;introduction of invasive species through human activities and natural encroachment;altered hydrology due to the impoundment and diversion of water; and changes to natural runoff from watersheds by human activities that alter the natural efficiency of watersheds and the permeability of soil surfaces. Increasing human demands on natural systems for consumable wildlife opportunities (such as hunting and fishing) and other recreational opportunities are also likely to continue to stress natural systems.

The pattern of persistence of native species in the Great Plains is likely associated with the regional pattern of agriculture and urban development. In the agriculturally rich,eastern portions of the Great Plains,the native habitats are absent or highly fragmented. In the central portion of the Plains,these habitats may still be present but are largely disconnected. In the western edges,the native habitats are often more continuous although the recent rapid expansion of urban areas along the Rocky Mountains is increasingly fragmenting these native communities. Persistence of species depends on sufficient habitat,sufficient core areas,or sufficient connectivity between habitat patches.

Invasive species are currently a significant issue on the Great Plains. Invasive species are plant or animal species that have been introduced into an environment in which they did not evolve and they usually have no natural enemies present to limit their reproduction and spread (Westbrooks,1998). Invasive species typically have high reproductive rates, fast growth rates,and good dispersal mechanisms. The costs and weed-associated losses in

Risk Management in the Northern Great Plains: Predicting Wheat Yield and Quality

Farmers have always monitored their crops closely for signs of nutrient deficiency, heat and water stress, insect infestation, and disease. With large acreages, however, it can be difficult to find the time to monitor all fields and even more difficult to follow change over a growing season and from year to year. Remote sensing has the advantage of being able to view large areas over one or several growing seasons. It can also detect radiation—for example, near-infrared (IR) radiation—which is invisible to the human eye. Plants absorb radiation in the visible red (R), but radiate it strongly in the near-infrared; how strongly depends on the plants' vigor and health. When vegetation indices, calculated from IR and R observations, are measured frequently over a season, the progression of canopy emergence, maturity, and senescence can be seen over large areas. The indices are also related to crop yields and, for grains, protein content. Real-time access to such data could be useful in agricultural and ranching operations.

Dryland wheat farmers and researchers in the Northern Great Plains used one vegetation index, the Normalized Difference Vegetation Index (NDVI), to see if protein content of wheat could be determined remotely during the 1998 growing season (Seielstad, 1999). Protein content, a measure of wheat quality, is related to existing soil nutrients, chemical inputs, plant biomass, and weather. The amount of nitrogen fertilizer required to produce a specific grain protein content is related to rainfall. In a wet year, early rapid plant growth will deplete soil nitrogen, resulting in a deficit late in the season and if additional nitrogen is not applied, the high yield will be of low quality. Conversely, late-season nitrogen application would not likely improve a crop's quality in a dry year.

With early information on weather and protein content of the crop, farmers could apply part of the total fertilizer typically needed for the entire growing season. The decisions about further fertilizer applications could be made as the growing season progresses. If less than average precipitation occurs or appears likely to occur, the initial fertilizer application may be sufficient. If growing season precipitation is predicted to be adequate for wheat production, then additional fertilizer to meet the growing needs could be applied. This management practice could save money, reduce runoff of unnecessary nitrogen, and lower the eventual emission of nitrogen into the atmosphere as a greenhouse gas.

Producer response was positive. In an article published in the Precision Agriculture Research Association (PARA) Newsletter, cooperating producers Carl and Janice Mattson write "...these NDVI images showed us the broad picture and gave us a great deal of optimism when it comes to satellite images. Perhaps with the more detailed images possible with the new satellites going up, there may be a vast amount of knowledge that we can apply to our management decisions." Several other producers also had positive responses. A similar study was applied to rangelands to develop efficient methods of assessing forage quantity and quality.

crop and forage production in the agricultural sector are nearly $15 billion annually. Introduced in 1827 as a contaminant in seed, leafy spurge occurs in all of the Great Plains states except Oklahoma and Texas. Grazing capacity of areas with more than 10 to 20% leafy spurge cover is significantly reduced (Westbrooks, 1998). The direct and secondary economic impacts of leafy spurge infestations on over 1.6 million acres in North and South Dakota, Montana, and Wyoming were approximately $129 million (Leitch et al., 1994). Crop losses in Kansas are annually $40 million from field bindweed (Westbrooks, 1998). 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 (Westbrooks, 1998).

In native ecosystems, invasive species may compromise the ecosystem's ability to maintain its structure or function (Stohlgren et al., 1999, Mack and D'Antonio, 1998, Vitousek et al., 1996). In grassland ecosystems, riparian areas next to streams and rivers are rich in native plant species and highly productive. These riparian areas are also critical habitat for species associated with the surrounding drier ecosystems, offering shelter and forage. These riparian ecosystems may be easily invaded by invasive species and may facilitate the establishment and migration of exotic plant invasions to upland sites in grassland ecosystems (Stohlgen et al., 1998). Natural

Agriculture Solutions to Global Warming

By Martin Kleinschmit, Farmer and Rancher, Bow Valley, Nebraska

Farmers have a lot at risk as global climate heats up, but they also have a lot to gain by participating in the solution to climate change. By conserving soil organic matter, farmers can improve soil health and productivity as well as capture and store (sequester) carbon in the extensive crop and rangelands of the Great Plains. The higher temperatures and greater numbers of droughts and floods projected for the region could threaten crops, raise production expenses, and increase the risk of failure. To protect our food supply, healthy soils able to withstand erratic weather patterns are needed. Increasing the carbon content of the soil will help to mitigate global warming by keeping carbon dioxide out of the atmosphere, but it will do even more to buffer the soil against the threats of climate change. Presently most US farmland has only half or less of its historical level of organic matter. Soil scientists have established that a 6-inch (15 cm) block of soil with 1-2% organic matter can hold only about one inch (2.5 cm) of rain before it runs out of the bottom. With 4-5% organic matter, that same soil can hold 4-6 inches (10-15 cm) of rain before it leaves the root zone and takes with it the water-soluble nutrients. Increasing soil organic matter also reduces the risks of flooding and erosion, and retains moisture longer so plants have access to it during periods of dry weather. It lessens the need for (and expense of) irrigation, reduces ground water pollution, and reduces the amount of run-off, lessening the threat of stream pollution. It also lowers the cost of fertilization since nutrients not lost to erosion and leaching need not be replaced. Agricultural incentives that encourage carbon sequestration in soil provide an opportunity to promote food security in a changing climate and reduce the threat of climate change at the same time.

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disturbance regimes such as fire and grazing are seen as important in maintaining the native species. Alteration of the frequency, intensity, spatial pattern, or scale of these disturbances may expedite the replacement of native species with exotics (Stohlgen et al., 1999). The loss of native species and the increasing presence of exotic or invasive species are current and continual challenges for natural resource managers of the Great Plains.

Potential Impacts

The projected climate changes will likely alter the biodiversity of the Great Plains. The “new” composition of species that might arise in response to the “new” climate may or may not be detrimental to society, but the rapid rate of change in climate is likely to be disadvantageous to native species. Invasive species exploit habitats left vacant by native species susceptible to multiple stresses. As climate changes, the indirect impacts of weeds and pests are likely to bring surprising challenges.

Some native species will be unable to adapt fast enough to new climate regimes, resulting in a lowered competitive edge and weakened resistance to infestations by invasive plants and animals. Potential impacts include shifts in the relative abundance and distribution of native species, significant changes in species richness and assemblages, and local extinctions of native species. Subtle changes in the diurnal or seasonal patterns of temperature have been shown to affect plant community composition. In the short-grass steppe, for instance, the slight warming of nighttime temperatures seen in the last 20 years has been linked to the decline of blue grama grass, the dominant grass of the short-grass prairie (Alward et al., 1999). Increased average temperature and annual precipitation in the Central Great Plains may make it possible for invasive plants, such as kudzu and Johnson grass, now found further south, to migrate north. Additional land-use pressure on these native systems is likely if agricultural practices extend into these areas as a result of more favorable climate or demands for agricultural products.

Changes, such as nutritional value of plants and changes in timing of insect emergence, may imply a decline in avian populations in the Great Plains, while longer growing seasons and the possibility of increased productivity may mitigate the declines (Larson, 1994). Grassland bird species are currently declining, a function of loss of habitat. Further alteration of their habitat from climate change would be a likely additional stress on these declining populations.

Changes in precipitation, temperature, and the hydrological cycle are likely to impact aquatic systems and the terrestrial animals dependent on these ecosystems. The abundance of wetlands is closely tied to the interannual variation in climate, both precipitation and temperature (Malcolm and Markham, 1998). Changes in annual precipitation in the northern regions are likely to have significant impacts on the breeding duck populations (Sorenson et al,. 1998;Bethke and Nudds,1995). Changes in precipitation and riverine flow regimes are likely to exacerbate land-use conflicts and competition for water supply including conservation needs.

Maintaining natural biodiversity—the full array of native plants,animals,natural communities,and ecosystems that occur within the Great Plains—may be difficult as climate changes. In the Northern Great Plains,the relatively undisturbed landscapes of the Indian reservations contain a variety of microenvironments supporting a wide range of indigenous plant and animal species. The scattered federal land holdings within the Northern and Central Great Plains also offer refuges for species and opportunities to enhance native vegetation. In the Southern Plains,however, there is very little protected land (Figure 1). The challenging issue in this area relates to private sector land management for ecotourism,and whether this is an appropriate route to maintaining some degree of biodiversity.

Adaptation Options

Rather than identify specific strategies,stakeholders in the Central Great Plains proposed a set of general principles to guide strategic development of social responses to climate change. These five principles were articulated as follows:

First,"no regrets"strategies,those that respond to existing stresses while making the system more resilient to climate change without incurring significant costs (OTA,1993),should be vigorously explored. There is a high level of uncertainty in regional climate projections and even greater uncertainty associated with how natural systems will respond to those changes. Developing detailed adaptation strategies based on predictions of future behavior of natural systems is currently not tenable. Instead,no-regrets strategies are particularly appropriate for natural systems because current environmental stresses could be addressed and mitigated through such strategies. The implementation of beneficial strategies today could have a positive influence on future stresses/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,such as landscape heterogeneity and high levels of connectivity in aquatic and terrestrial systems. Landscape heterogeneity is the diversity among ecosystems,such as grasslands and forests,and within ecosystems,such as different successional stages. This latter type of diversity depends on maintaining appropriate disturbances to the ecosystems,such as periodic fire. In many cases,disturbance activities need to be created by management actions,such as livestock grazing and prescribed burning,in order to compensate for the loss of natural disturbance regimes,such as buffalo herds and 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 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 is adaptive management. The stakeholders felt that it is critically important to learn by doing and to evaluate what works and what fails to work in an attempt to lessen the impact(s) of climate change on natural systems. There will be surprises no matter how well prepared stakeholders may be;therefore management that is flexible and responds quickly will be most effective for dealing with uncertainties.

Finally, effective coping strategies depend on informing the public and decision makers about the implications of climate change for natural systems,and what these effects mean to the quality of human life. For example,why is the role of wetlands in flood control important to society? What could changes in this natural system mean to a community or to natural systems on local and regional bases?

The stakeholders saw these principles as fundamental to the discussions of climate change in all regions and an effective way to educate the general public and decision-makers about the related issues involved with climate change.

4. Quality of Rural Life on the Great Plains

Current Issues

Current demographic changes are imposing challenges to the rural areas of the Great Plains. Declining rural populations,the aging of remaining residents,and the increased remoteness of neighbors place rural communities at increased socioeconomic risk. The growing urban areas are magnets for jobs and people. This shift in population increases the demand for services in urban areas, while increasing the burden on rural governments to provide health and education services with a declining economic base. The vulnerability of the rural human populations on the Great Plains will affect their ability to marshal resources,both natural and societal,to cope with increased risk and uncertainty. As the urban centers continue to grow, problems such as air quality will likely compromise the quality of life in urban areas,including the health-related aspects (see Additional Issues).

The consequences of weather and change on agricultural economics,beef cattle production,and grassland use can be subtle and complex due to indirect impacts from international trade,cost of feed,and markets. Most agricultural commodities are subject to production/price cycles,with the time between peaks and troughs of production controlled largely by the producer's ability to respond to price signals and consumer behavior. However, climate variability, especially drought,can significantly modify the dynamics of cattle inventories and production/price cycles, resulting in losses to producers. For example,the 1995-96 Texas drought resulted in larger numbers of cattle being sent to market due to poor range condition,increased corn feed prices,and the largely diminished winter wheat feed crop.

Potential Impacts

The projected changes in climate – increases in temperature, reductions in soil moisture,and more intense rainfall events – will likely require changes in crop and livestock management in the Great Plains. Because rural populations and their communities are highly dependent on the natural resources of the Great Plains,they are at risk from climate change,and from potential increases in climate variability. Rural economies in semi-arid regions are economically vulnerable due to lower marginal economies (lower profits and tax bases, fewer resources available) and their reliance on livestock and cropping systems that are often stressed. International exports will reflect the climate change impacts on the global agricultural markets.

Increases of warm-season forages may be a welcome addition to a forage mix in the Northern Great Plains,but the loss of the current diversity of warm- and cool-season forages in the Central Great Plains may pose limitations in grazing management. The elevated atmospheric concentration of carbon dioxide will possibly lower forage quality of native grasses. Legumes,a potential source of nitrogen,could be a new and important part of farm and ranch management. Changes in the seasonality of precipitation,particularly the growing season precipitation, will likely impact plant growth of native vegetation and crops with and without irrigation in the Great Plains. Warmer winters will mean some chance of

Table 1. Soil and Water Conservation Strategies and their Benefits
(Soils Working Group,Ojima et al.,1997).

Adaptation Action	Benefits to Farmer/Rancher	Benefits to Climate Change Issue
Soil organic matter management	Increase in water-holding capacity Increase in soil fertility	Increase in soil carbon storage
Precision Farming		Reduction in N_2O emissions
Targeted fertilizer application	Cost savings	
Targeted water application	Cost savings/reduced salinization	
Targeted pesticide application	Cost savings/reduced toxification	
Energy from biomass	Diversified	Reduction in carbon dioxide emissions from fossil fuel burning
Managing livestock wastes to capture methane	Usable energy	Reduction in methane emissions

more rain than snow with resultant deeper recharge,enhancing the competitive advantages of shrubs. More intensive storm activity and an increased frequency of heat waves will likely be an increasing problem for the Southern Great Plains. Whether or not the plant community will be able to accommodate changes in growing season climate or hydrological patterns is a matter of concern among stakeholders who depend on these weather patterns for their livelihood.

Adaptation Options

The stakeholders in the Great Plains proposed that the most effective adaptation strategies would be "no regrets"actions,developed from the bottom-up through community-based efforts,with an emphasis on risk reduction and increasing diversification. Because each community has different needs and values,a community-based approach was strongly supported to address issues related to adaptation and mitigation of climate change and variability. Stakeholders identified that any government policy directed towards responding to climate change at the national scale should focus on the long-term,not short-term economic incentives;should be flexible, allowing for local implementation and short response times;and should promote adaptation strategies that are sustainable and economically viable.

In the agricultural sector, various strategies have evolved to cope with drought and soil erosion (Ojima et al.,1997). Many of these coping strategies not only provide direct benefits to the farmer or rancher, but are also beneficial to the environment (Table 1). The loss of carbon and water from croplands can be minimized through practices such as reduced tillage. Cover crops and residue management can facilitate soil conservation by suppressing soil loss from wind and water erosion. Precision agricultural practices that integrate specialized crop varieties, fertilizer inputs,and irrigation schedules into crop management may provide technology to cope with climate changes.

Stakeholders also spoke about diversification,how this strategy had helped in coping with other climate or economic events in the Great Plains,and what institutional factors limited the ability of people in the Great Plains to diversify their operations and their local and regional economies. Livestock enterprises are often a mix of range management and planted forage or crop activities. Stakeholders identified diversification of land use as an important strategy to increase profits and/or reduce risk. Examples included a strategy that some operators have already adopted such as diversifying ranch operations to include recreation,or a new strategy that policy makers could implement such as carbon credits. In addition,stakeholders identified the importance of diversification within a land use, such as ranching,to cope with the effects of climate change. Diversification strategies included 1) mix or change animal species to fit the new environment,2) change genetics of the animal species, 3) change seasonality of production (e.g.,calving, lambing, weaning),or 4) reduce production practices in stressful environments.

ADDITIONAL ISSUES

- Industrial and urban infrastructures designed for historical climate extremes may be inadequate under a different climate. As the Great Plains continues to change due to social and economic factors,demands on the existing water resource structures and other social infrastructures will also change and further challenge resource allocations in the future for land and water. In addition, climate change will affect long-term planning regarding current capacity or future design of additional infrastructure needs to sustainably utilize water and land resources. For example, in the Southern Great Plains, researchers have been working with urban engineers to assess unexpected impacts on urban infrastructures from recent extreme events,and to develop adaptation strategies for future events.
- Across the Great Plains,the poor living in communities of all sizes are disconnected from some of the most essential safety nets to cope with natural hazards. The human mortality that results from severe heat waves, floods,and natural hazards is a problem that eludes the best-intentioned policies. For example,in the Southern Plains,the poor along the Lower Rio Grande are extremely vulnerable to both droughts and flash floods. The relationship between poverty and carrying capacity of the environmental system is not a typical part of a community's approach to developing social service systems. The current struggle to achieve a sustainable economy that properly takes account of ecosystem services and social services will likely become an increasingly important issue.
- Rising air temperatures will exacerbate the current air quality issues in the urban areas of the Great Plains. Denver (and much of the Colorado Rocky Mountain Front Range) suffers serious air quality problems on a seasonal basis. Every

major city in Texas is out of compliance with current air quality standards. Houston is the second most polluted city in the nation. Typically, in Texas,a longer warm season will produce more days exceeding air quality standards. This is an immediate issue in Texas because these cities will either lose federal funds in the next decade due to their inability to control emissions,or will spend millions of dollars in courts trying to challenge regulatory penalties. The problems are exacerbated by rising urban populations from population growth as well as rural migration to cities for jobs. The issue of air quality has the potential to be an international issue if situations such as the 1998 wildfires in Mexico that inundated the Great Plains with smoke and dust become more frequent under an altered climate. Major air quality impacts occurred in the Rio Grande and Southern Great Plains and plumes from these wildfires were transported as far north as Canada.

- Advancements in technology have improved farming capability. Partnership in global change research and advancement of these technologies should provide a greater buffer against perturbations to the agricultural ecosystems and economy.
- Dissemination of information on adaptive varieties of crops and livestock suitable for changing conditions is needed from reliable sources for stakeholders.

CRUCIAL UNKNOWNS AND RESEARCH NEEDS

Research needs identified for the Great Plains focused on improvement of weather forecasts, enhancement of diversification in agriculture,management of the biodiversity of native ecosystems, improved water allocation decision-making tools, improved pest management strategies,carbon sequestration techniques,and human dimensions research.

Monitoring,early detection,and distributed warning of extreme weather events would allow for preparation and responses to minimize damages. Interannual and seasonal forecasts of weather would improve advanced planning of many activities:what crops to plant,how many cattle to graze,and other management activities. Increased research on the incidence and possible timing of hail in the Great Plains would benefit farmers by helping them make more informed decisions about their cropping plans under the forecasted climatic conditions.

For native species,there is a need to synthesize currently available information about the potential impacts of climate change on native species and natural systems. This would include quantifying the ecological and physiological thresholds of native organisms and their tolerances to changes in environmental factors such as temperature,salinity, and sedimentation,and developing coordinated cropping/grazing systems that minimize impacts at critical periods for wildlife reproduction. Given that many natural systems in the region are substantially altered by human activities, research is needed on restoration techniques that will be effective to restore biological diversity and ecosystem services to degraded systems.

A better understanding of the relationship between livestock dynamics and rangeland condition,and the role that the diversity of both plant and animal components of rangeland ecosystems play in maintaining good rangeland condition is a needed area of research. Studies of climate change and elevated carbon dioxide levels on vegetation and animal dynamics are needed to understand ecosystem-level responses. Climate change will interact with the other current stresses on these native ecosystems and it is the cumulative effects of multiple stresses on natural systems that needs greater understanding and the development of management tools.

For agriculture, research is needed on the best feasible methods of diversification under certain climatic conditions and in specific localities. Soil types, rainfall,and growing seasons limit agricultural diversification. For example,including leguminous crops, like field peas,lentils and Austrian winter peas,in crop rotations has been successful in the Northern Plains but of limited value in the Central Plains.

Research on new crop and crop variety development for a future climate involves long lead times. 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 seeds which are better adapted to the new climate are produced, tested,and marketed. With new crops come new pests,and these need to be taken into consideration when new seed is developed.

The attainment of viable management practices for storing carbon and conserving Great Plains lands and aquatic areas is a complex issue,and will require new knowledge. Research is needed to understand the carbon cycle in the context of the ecology of Great Plains'ecosystems and agro-ecosystems,with the objective of using that information to develop conservation systems that lead to carbon storage and soil conservation. The role of wetlands in sequestering carbon needs to be better understood. Economic research is also needed to start to understand how best to achieve the goal of promoting sustainable management practices including carbon sequestration.

Research Needs Related to Humans in the Great Plains

All of the previously mentioned research will also enhance human-managed systems in the Great Plains,as the health of natural systems is vital for human quality-of-life and for recreational activities. Water quality issues are important for rural settlements,as are water supply issues. Diversification may be an important tool for survival of many family farms and ranches in the Plains,and better forecasts may encourage human preparedness for extreme events in the Plains.

There are however, several additional research needs that focus on the human populations of the region (cf Stern and Easterling,1999). These include comprehending the perception of, understanding of, and awareness of climate change and its impacts in different parts of the Great Plains. A survey should be conducted to determine respondents'perceptions of whether and how climate has changed,how they monitor it,how it has affected their livelihoods,and if they have made any changes as a result.

Involving local people in designing and implementing the monitoring of climate change is important. Stakeholders can provide input to scientists regarding what types of information and forecasting are needed at the local level. This can make research more valuable to the farmer/rancher and provide an opportunity for scientist-practitioner interaction. Variables that may require study include soil organic matter, soil moisture,plant productivity, and extreme event frequency.

Rural residents other than farmers or ranchers,those living in urban areas,and those that depend on the Plains for products may also be affected by climate change. These affects should be a further area of research on human dimensions. How climate change affects demographic patterns in the region,both urban and rural (specifically age structure and employment) would also be an important research topic. Many people enjoy recreation in the Plains, and people all over the country depend on farm products from the Plains. Therefore, changes that affect the Plains will have indirect effects spread widely throughout the US and the world.

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ACKNOWLEDGMENTS

Materials for this chapter are based in large part On the products of workshops and assessments carried out by the

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